Energy Savings from Honeywell Total Connect Comfort Thermostats—Estimates from 2nd National Impact Study

August 18, 2015

Prepared for:

Smart Grid Solutions
Honeywell International Incorporated
1985 Douglas Drive North
Golden Valley, MN 55422

The Cadmus Group, Inc.
An Employee-Owned Company • www.cadmusgroup.com
This page left blank.
This page left blank.
# Table of Contents

Executive Summary .................................................................................................................... 1

Introduction .............................................................................................................................. 1

Research Methods .................................................................................................................. 1

Main Findings .......................................................................................................................... 2

How This Paper’s Results Should Be Used ............................................................................. 3

Introduction .............................................................................................................................. 4

Honeywell Total Connect Comfort Thermostats ....................................................................... 4

Research Questions ................................................................................................................ 5

Energy Policy Relevance .......................................................................................................... 6

Organization of This Report .................................................................................................... 7

Methodology ............................................................................................................................ 8

Overview .................................................................................................................................. 8

Analysis Steps .......................................................................................................................... 9

  Step 1: Develop Home Space Conditioning Energy-Use Models ............................................ 10

  Step 2: Match TCC homes to RECS homes ......................................................................... 10

  Step 3: Estimate Models of Home Energy Use for Heating and Cooling ............................. 13

  Step 4: Determine the Effect of TCC Thermostats on Temperature Set Points ................... 14

  Step 5: Estimate Energy Savings ......................................................................................... 16

TCC Thermostat Energy Savings Estimates ............................................................................ 18

Differences in Thermostat Interior Temperature Set Points...................................................... 18

Energy and Energy Cost Savings from TCC Thermostats ....................................................... 20

  Comparison to Savings Estimates from First National Impact Study ................................. 22

  Regional Savings Estimates .................................................................................................. 24

Cost-Effectiveness of TCC Thermostat Adoption .................................................................... 27

  Cost of Saved Energy for Utility Connected Thermostat Efficiency Programs .................. 28

How The Paper’s Results Should Be Used .............................................................................. 30

Conclusions ............................................................................................................................. 32

Summary of Main Findings ....................................................................................................... 32

References .................................................................................................................................. 34
This page left blank.
Executive Summary

Introduction
In the United States, space conditioning constitutes the largest residential energy end use. According to the most recent U.S. government estimates, space heating and cooling account for, respectively, 42% and 6% of residential energy use. Consequently, policymakers looking to slow the increase in U.S. energy consumption have focused on achieving efficiency improvements in residential space conditioning.

An opportunity exists to reduce residential energy use by enhancing occupants’ control of home space heating and cooling. In the past few years, Honeywell and other thermostat manufacturers have introduced a new generation of residential space-conditioning control technologies: wireless, two-way communicating, programmable thermostats.

Users can control these thermostats from a thermostat keypad or from a web or mobile device. Programmability and enhanced controls afforded by WiFi-enabled thermostats reduce the costs of controlling home space conditioning systems and offer potential energy savings by enabling users to better align space conditioning with home occupancy or demand.

In October 2014, Cadmus released a study that estimated energy savings from adoption of Honeywell connected thermostats, based on an analysis of user interface data for approximately 800 of these thermostats. This initial report found that Honeywell Total Connect Comfort (TCC) thermostats saved about 7% of energy used in space heating and cooling and that annual energy cost savings averaged $116 per home. The report also found significant differences in energy and cost savings between regions of the United States.

This paper updates that original analysis with new savings estimates, based on an analysis of a much larger sample of thermostats. Cadmus analyzed user interface data between August 2013 and July 2014 for over 34,000 Honeywell TCC thermostats. Cadmus also applied methodological improvements for the second study, though the basic approach remained unchanged.

This updated whitepaper uses rich data about user interactions with Honeywell connected thermostats from this larger data set to better understand the thermostats’ impacts on home energy use.

Specifically, the paper answers three main questions:

1. What home space heating and cooling energy savings do Honeywell TCC thermostats produce?
2. What energy cost savings do TCC thermostats produce? Is it cost-effective for homeowners to adopt the thermostats?
3. How do energy and cost savings from TCC thermostats vary between regions of the United States?

Research Methods
In standard engineering models, annual energy use for home space heating or cooling can be expressed as a function of the home’s average thermostat set point. To estimate energy savings, Cadmus
compared average thermostat set points in homes with and without connected thermostats and translated the resulting differences into space heating and cooling energy savings.

Cadmus estimated baseline set points using household data from the 2009 U.S. Department of Energy’s Residential Energy Consumption Survey (RECS). This large, nationally representative survey examined different aspects of home space heating and cooling, including typical thermostat set points, occupancy schedules, energy use, and heating equipment types and fuels. The baseline included thermostat set points from a mix of RECS homes with programmable and nonprogrammable thermostats and was similar to the residential customer populations of many utilities. Thermostat set points reported in the survey constituted a valid baseline because the 2009 RECS preceded widespread introduction of connected thermostats.

To minimize the potential that self-selection of TCC thermostat users could bias the comparison of set points, Cadmus used a matching procedure—Coarsened Exact Matching—to identify RECS households with energy use characteristics similar to those of TCC thermostat households. Cadmus matched TCC thermostat homes to RECS homes on the basis of variables expected to strongly influence space conditioning energy use: household income, home size, climate zone, and state. This matching procedure increased the likelihood that differences in average thermostat set points between homes with and without TCC thermostats represented a causal effect, not the effect of adopters’ characteristics that both made them more likely to purchase a TCC thermostat and to choose particular set points. Cadmus performed the analysis on the matched observations of RECS and TCC thermostat homes to estimate TCC thermostat energy savings.

Cadmus developed econometric models of home space heating and cooling energy use to estimate savings from TCC thermostat adoption as a function of the difference in average thermostat set points. Cadmus derived these models directly from engineering models of home space heating and space cooling energy use. We used RECS data to estimate the model and the relationships between thermostat set points and space conditioning energy use.

Based on this analysis, we estimated average annual energy savings and cost savings per home for the United States, including estimates for ten U.S. census divisions. We also estimated the length of the payback period required for energy cost savings to cover the incremental costs of a TCC thermostat and the average cost of energy savings for a typical utility running a connected thermostat program.

**Main Findings**
On average adopters of Honeywell TCC thermostats saved significant energy and energy costs. Also, adoption proved highly cost-effective for many homes in the United States.

Specifically, the energy savings analysis produced the following findings:

- Homes with Honeywell TCC thermostats had lower average set points during the heating season (-1.4°F) and higher average set points during the cooling season (+1.3°F) than homes with programmable or nonprogrammable thermostats.
On average, Honeywell TCC thermostats saved about 8% of energy use for home space heating and 17% of energy use for home space cooling during a normal weather year. In total, TCC thermostats saved about 9% of annual energy use for space heating and cooling.

Honeywell TCC thermostats saved about $45 per home per year in space heating energy costs and $90 per home per year in space cooling energy costs during a normal weather year. Total energy cost savings were $135 per home per year.

Energy and energy cost savings varied significantly between regions. Homes with long space heating and space cooling seasons saved the most energy and realized the greatest energy cost savings.

Homes in the Mid-Atlantic, South Atlantic, and West South Central census divisions achieved the greatest space conditioning energy savings. Estimates of the combined average space-heating energy cost savings and average space cooling energy cost savings in these regions were, respectively, $142, $190, and $197 per home per year.

Adoption of TCC thermostats proved cost-effective for many adopters. In most regions, the TCC thermostat annual energy cost savings exceeded or just equaled the incremental costs of TCC thermostats. Adopters achieved a positive return on their investments after approximately one year.

The levelized cost of space cooling energy savings for a utility direct-install program featuring Honeywell TCC thermostats would be $0.09 per kWh under a low-cost program scenario and $0.15 per kWh under a high-cost program scenario, which both exceed the median levelized cost of saved electricity ($0.06/kWh) for utility residential whole-home or direct-install programs in the United States (LBNL, 2014). However, utilities in the East South Central, Mountain-North, South Atlantic, and West South Central census divisions would have levelized costs only slightly greater than the national median.

How This Paper’s Results Should Be Used

This study provides energy savings estimates from connected thermostats for different regions of the United States. Further, it provides valuable information about savings and cost-effectiveness for utilities and regulators considering connected thermostat programs.

As connected thermostats are new product offerings, relatively little information exists about expected energy savings. This national study helps fill that void by providing estimates of energy and cost savings that utilities across the United States can expect from Honeywell connected thermostats.

This study is intended primarily to assist utilities and regulators with their efficiency program planning. It should not serve as a substitute for carefully designed field studies of energy savings provided by connected thermostats. Utilities still need to conduct their own EM&V to verify expected savings.

Finally, the study only considers space heating and space cooling energy savings. It does not consider address potential benefits to utilities of using Honeywell TCC thermostats to manage residential space-conditioning loads to obtain peak-demand savings.
Introduction

For most homes in the United States, space conditioning constitutes the largest energy end use. Per the most recent U.S. government estimates, space heating and cooling account for, respectively, 42% and 6% of residential home energy use.¹ Although space conditioning’s share of residential energy consumption will likely decrease, energy used per home for residential space conditioning will grow due to increased saturation of central air conditioning.

Consequently, policymakers looking to slow the increase in U.S. energy consumption have focused on achieving efficiency improvements in residential space conditioning. Policies aimed at increasing space heating and cooling efficiency have worked effectively, encouraging adoption of better insulation, double-paned windows, and efficient furnaces, heat pumps, and air conditioners.² Despite these achievements, significant opportunities remain to reduce energy use for home space conditioning.

Enhancing user control of home heating and cooling systems provides an avenue for increased energy savings. In the 1990s, the U.S. government’s ENERGY STAR program encouraged adoption of programmable thermostats, which allowed users to schedule heating and cooling in their homes; energy savings from programmable thermostats, however, have proved elusive.³

During the past few years, Honeywell and other thermostat manufacturers have introduced a new generation of residential space-conditioning control technologies: wireless-communicating, programmable thermostats. Users can use these thermostats to control their heating and cooling system remotely via a thermostat keypad or a web or mobile device. The enhanced control afforded by WiFi-enabled thermostats reduces control costs and creates potential energy savings by enabling users to better align home occupancy patterns with space heating and cooling.

Honeywell Total Connect Comfort Thermostats

This study estimates energy savings from programmable, WiFi-enabled Honeywell Total Comfort Connect (TCC) thermostats. Honeywell introduced the first TCC thermostats in 2012. Wall-mounted, two-way communicating, and programmable, TCC thermostats offer a user interface and mobile and web applications. These applications allow users to connect and adjust thermostat settings remotely via phone, tablet, or computer. Figure 1 shows a recent TCC thermostat model.

² For example, see Aroonruengsawat, Auffhammer, and Sanstad (2009) and Jacobsen and Kotchen (2010).
Honeywell designed TCC thermostats to provide the following features:

- Mobile connectivity for remote user-control of the thermostat;
- Ease of use and programming compliance; and
- Third-party communication and control for utility direct-load control programs.

Honeywell sells TCC thermostats through retail, trade, and utility channels. Homeowners purchase connected thermostats for a variety of reasons, including increased convenience of use, enhanced thermal comfort in the home, and reduced household energy use and costs.

**Research Questions**

While the connected thermostats’ mobile connectivity increases convenience and reduces costs of controlling home space heating and cooling, their impact on energy use remains less certain.

To understand potential impacts, consider a typical U.S. household using a traditional programmable or non-programmable thermostat and seeking to maintain the home’s interior at a particular temperature. The preferred temperature may change with the season, day of the week, and hour of the day, and may depend on the home’s occupancy, occupants’ thermal comfort, and energy costs. The cost of controlling the thermostat, requiring users to be in the home, may prevent them from achieving their preferred temperatures, and the home may be too hot or too cold.

Mobile connectivity can help users to achieve their preferred temperatures. Enhanced thermostat control affects energy use for heating and cooling along two margins:

- First, thermostat users may heat or cool a space-conditioned home more or less intensively (i.e., cool or heat the home to a higher or lower temperature).
- Second, thermostat users may increase the amount of time (e.g., the number of days or hours during the year) that they heat or cool the home.
Energy savings occur if mobile connectivity causes a net decrease in heating or cooling energy use due to changes on either margin. As noted, mobile connectivity may allow users to better align home heating and cooling with occupancy patterns. For example, users can remotely override scheduled set points to switch space heating or cooling systems off when they are away from home longer than expected. Also, by reducing control costs, mobile connectivity also may allow users to heat or cool less while the home is occupied. Using a mobile phone application, energy-efficient temperature set points can be adjusted in the home without visiting the wall-mounted unit. To the extent that wasteful heating and cooling can be eliminated without sacrificing thermal comfort, reductions in energy use would represent an unambiguous increase in efficiency.

Ultimately, however, energy savings from connected thermostats remain an empirical question that can be answered only by studying how people use them. This paper seeks to use data about user interactions with Honeywell connected thermostats to better understand the thermostats’ impacts on home energy use. Using data for a much larger number of connected thermostats, this paper updates savings estimates presented in the original Cadmus study, released in October 2014.

Specifically, this paper answers three questions:

1. What home space heating and cooling energy savings do Honeywell TCC thermostats produce?
2. What energy cost savings do TCC thermostats produce? Is it cost-effective for homeowners to adopt TCC thermostats?
3. How do energy and cost savings from TCC thermostats vary between regions of the United States?

Cadmus addressed these questions by collecting thermostat temperature set point data from homes with TCC thermostats and from homes without TCC or other connected thermostats. Annual energy use for home space heating and cooling can be expressed as a function of the average thermostat set point according to standard engineering models. Cadmus collected user-interface (UI) data from 2013 and 2014 for over 34,000 Honeywell TCC thermostats in homes across the United States. The UI data provided a rich source of information about how Honeywell TCC thermostat adopters heated and cooled their homes. To establish a baseline for connected thermostat use, Cadmus analyzed household survey data on thermostat set points from the 2009 Residential Energy Consumption Survey (RECS). The RECS baseline included a blend of programmable and non-programmable thermostat homes that had similar sizes, household incomes, and locations as TCC thermostat homes. Cadmus then translated the difference in average set points into estimates of space heating and cooling energy savings from TCC thermostats using econometric models derived from engineering models of home space conditioning.

**Energy Policy Relevance**

Energy savings from connected thermostats merit study as the United States faces a growing imperative to increase energy efficiency and reduce greenhouse gas emissions. Many states have set energy-efficiency portfolio standards that mandate annual reductions in energy use against a baseline. The federal government and states also have set increasingly stringent energy efficiency building codes and appliance standards, establishing minimum efficiency levels for new building construction and
appliances. The U.S. Environmental Protection Agency’s (EPA) proposed rule 111-D, regulating emissions from existing thermal power plants, also encourages states to reduce emissions by increasing site (end-use) energy efficiency as well as efficiency of thermal electric generators.

This imperative has left regulators, policy makers, and utilities responsible for implementing efficiency policies searching for new opportunities to increase residential energy savings. The residential sector accounts for 22% of national end-use energy consumption, and, as noted, space conditioning remains the largest residential energy end use. Thus, space conditioning obviously presents a potential source of energy savings, and connected thermostats may offer a means to achieve some of these.

Little evidence exists, however, about energy savings available from connected thermostats. The technology remains new, and industry has commissioned few energy-savings studies. Several utilities plan to operate (or are operating) pilot programs to test energy savings from connected thermostats, but, while these studies will provide valuable evidence, they address a small scope and may have limited applicability in other areas of the country.

This study offers an advantage over pilot program analysis in covering the entire United States and providing estimates of energy-use savings for both heating and cooling.

**Organization of This Report**

Cadmus organizes this report as follows:

- The second (next) section describes the study methodology, including model development, data collection, model estimation, and energy and cost savings estimations.
- The third section presents estimates of the differences in thermostat set points between homes with and without Honeywell TCC thermostats and estimates of energy and energy cost savings from connected thermostats.
- The fourth section concludes the paper by presenting the study’s main findings.
Methodology

Overview
Honeywell provided Cadmus with UI data for approximately 140,000 TCC thermostats installed in U.S. homes. Each thermostat was installed and registered before July 2013 and provided 12 months of UI data, collected between August 2013 and July 2014. Users purchased the thermostats from retail outlets or home space-conditioning contractors. As connected thermostats represented a relatively new product offering during the study period, TCC thermostat purchasers can be considered early adopters.

The UI data provided a rich view of how users interacted with their connected thermostats. When a TCC thermostat senses an automatic or manual change to thermostat settings or a change in the home’s environment, the thermostat sends a report to Honeywell. This report includes a timestamp, heating and cooling temperature set points, the home’s interior temperature, the outdoor temperature, indoor humidity, outdoor humidity, the relay status of heating and cooling systems, schedules for home heating and cooling, and other fields. A thermostat may generate a few to a dozen reports per hour and thousands or tens of thousands of reports per year.\(^4\)

While rich in information about households’ thermostat use, the UI data presented some limitations for estimating energy savings from connected thermostats:

- First, the data did not provide direct information about space conditioning energy use.\(^5\)
- Second, the UI data only covered the post-adoption period and did not include information about thermostat settings prior to adoption.

To establish a baseline for TCC thermostats, Cadmus relied on data from the U.S. Department of Energy’s (DOE) RECS. In 2009, DOE surveyed 12,083 U.S. households regarding different home energy end uses, including about the following:

- Space-conditioning equipment type;
- Thermostat type (programmable or non-programmable);
- Thermostat settings by season and time of day;
- Occupancy patterns; and
- Housing characteristics (e.g., floor space, number of floors).

Cadmus used information about thermostat set points in RECS homes with programmable or non-programmable thermostats to establish a baseline for TCC thermostat homes. The 2009 RECS provided a valid baseline as the survey preceded the widespread market adoption of connected thermostats.\(^6\)

---

\(^4\) UI data in the analysis sample did not include information on whether users accessed a TCC thermostat with a mobile device or via the web, as opposed to a thermostat touchpad.

\(^5\) As most users purchased thermostats through a retailer or home space-conditioning contractor and not a utility program, utilities could not provide data on home electricity or gas use.
As this study relied on a comparison of temperature set points between homes with and without TCC thermostats, any preexisting characteristics causing households to adopt TCC thermostats and to choose particular temperature set points could bias the savings estimates and present a threat to the study's internal validity.

For example, TCC thermostats adopters could have been more likely to have been employed and thus to lower their heating set points while at work. Therefore, TCC adopters would select lower heating temperature set points, regardless of thermostat types in their homes. If the analysis did not account for this characteristic of adopters, the savings estimates could be biased.

To minimize the potential for such bias, Cadmus used a matching procedure—Coarsened Exact Matching (CEM)—to identify RECS households with similar incomes, home sizes, climate zones, and locations as homes with TCC thermostats. This step preceded estimating differences in thermostat set points between homes with and without connected thermostats and translating the differences into energy savings. This matching procedure reduced the likelihood that differences in estimated thermostat set points between homes with and without connected thermostats resulted from unrelated confounding factors.

Cadmus used information in the RECS to estimate relationships between temperature set points and space heating and cooling energy use. Cadmus developed econometric models directly from engineering models of energy use for home space heating and cooling and estimated these using data on RECS homes matched to TCC thermostat homes. Energy savings from connected thermostats were then estimated as a function of the difference in average set points between homes with and without connected thermostats.

**Analysis Steps**

Specifically, Cadmus estimated energy savings from TCC thermostats using the following five steps:

1. Develop models of energy use for home space heating and cooling.
2. Match TCC thermostat homes to RECS homes using CEM.
3. Estimate cooling and heating energy-use models with matched RECS data.
4. Determine thermostat set points for TCC and RECS homes.
5. Estimate energy savings as a function of the difference in set points between TCC and RECS homes.

The remainder of this section describes each of these analysis steps in greater detail.

---

6 Cadmus analyzed data from RECS surveys in the 1990s and 2000s to check for trends in thermostat set points that would invalidate the baseline. After controlling for household income, home size, and home location, we could not identify trends in thermostat set points.
Step 1: Develop Home Space Conditioning Energy-Use Models

Cadmus first developed econometric models of home energy use for space heating and cooling. The models related space conditioning energy use to average thermostat temperature set points.

Cadmus derived the estimating equations directly from engineering models of energy use for home space heating and cooling. These models accounted for the following:

- The home envelope area;
- Exterior wall and attic ceiling thermal efficiency;
- Space-conditioning equipment efficiency; and
- The difference between the average thermostat set point and the average outdoor temperature.

The estimating equations took the following form:

\[ e = g(\text{ceiling area} \times \Delta T, \text{wall area} \times \Delta T, \text{equipment type}) \]  

(Equation 1)

Where:

- \( e \) = Average energy use per hour for space heating (cooling) in kBTUs in the home.
- Ceiling Area = Estimate of the home attic ceiling area in square feet.
- \( \Delta T \) = The difference between the average thermostat set point and the average outside temperature.
- Wall Area = Estimate of home exterior wall area in square feet.

The coefficients in the heating (cooling) model indicated average energy use per hour, per square foot of floor space, for each degree of difference between the thermostat set point and outdoor temperature. The coefficients had an explicit interpretation for home space heating or cooling: they represented the product of the average R factor for the home’s envelope and the efficiency of the home’s space-conditioning equipment.

Step 2: Match TCC homes to RECS homes

Cadmus next developed the RECS analysis sample used to establish a baseline for connected-thermostat homes. This involved using the CEM procedure to identify households in the 2009 RECS with energy-use characteristics similar to those who adopted connected thermostats.\(^7\) We expected households with the greatest expected benefit from adopting a connected thermostat would be the most likely to purchase one. Such households likely had high demand for space heating and cooling.

Cadmus used CEM (as discussed, a matching procedure used in social scientific research for estimating causal effects) to identify RECS homes that were most like adopters. CEM reduces imbalances between a treatment group (e.g., TCC thermostat homes) and a comparison group (e.g., RECS homes), thus

\[^7\text{See Iacus, King, and Porro (2012) and King, Gary, Richard Nielsen, Carter Coberley, James Pope, and Aaron Wells (2011).}\]
increasing the likelihood that the treatment, not some extraneous factor, caused observed differences in the outcome variable between treatment and comparison groups.

CEM involves the following four steps:

1. Determine the matching variables.
2. Coarsen each matching variable by creating bins for mutually exclusive ranges of values for the variable. For example, the home floor area might fall into one of six mutually exclusive ranges.
3. Identify treatment and control group observations that exactly correspond in terms of coarsened matching variables.\(^8\) These observations belong to the same stratum, defined by specific ranges or bins for each matching variable.
4. Drop the coarsened data and perform analysis only on matched observations using original data. Drop any observations that could not be matched using the coarsened data.

In performing CEM on TCC thermostat and RECS homes, Cadmus used the following variables:\(^9\)

- Household income
- Home floor space (sq. ft.)
- Reportable domain\(^10\)
- Building America Climate Zone\(^11\)

These variables were principal drivers of home space heating and cooling energy use. Cadmus obtained data on these variables for TCC thermostat homes from InfoGroup, a supplier of household-level data on demographics and housing characteristics; the 2009 RECS provided information about the same variables for surveyed homes.\(^12\)

Table 1 shows the matching procedure results for TCC thermostat and RECS homes. After matching, the final analysis sample included 34,043 TCC thermostat homes and 3,356 RECS households.

\(^8\) In conducting the analysis, Cadmus applied these CEM procedure weights, which control for differences in the numbers of treated and control units.

\(^9\) Before performing the matching, Cadmus limited the RECS and TCC thermostat analysis samples to detached, single-family homes, as the space heating and cooling energy use models apply best to homes of this type.

\(^10\) Reportable domain is a RECS variable that indicates the location of the home in one of 27 states or small groupings of states (e.g., Kansas, Nebraska, North Dakota, and South Dakota).

\(^11\) Building American climate zone definitions can be found online: http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_climateguide_7_1.pdf

\(^12\) Cadmus limited the number of variables for matching as additional variables would have resulted in excessive attrition of TCC thermostat homes from UI data. Many TCC thermostat homes had missing values for one or more variables in the InfoGroup data and therefore could not be matched to the RECS.
Table 1. Matched Analysis Samples

<table>
<thead>
<tr>
<th>Table Heading</th>
<th>Before CEM</th>
<th>After CEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCC thermostat homes</td>
<td>139,945</td>
<td>34,043</td>
</tr>
<tr>
<td>RECS households</td>
<td>12,083</td>
<td>3,356</td>
</tr>
</tbody>
</table>

After matching, TCC thermostat homes and RECS households exactly matched in terms of the coarsened values of household income, home floor space, reportable domain, and climate zone. Cadmus also found strong correspondences when comparing matched TCC thermostat and RECS homes on the basis of other variables not used in the matching, such as household head age and home vintage.

Figure 2 displays county locations of matched TCC thermostat homes. Darker shades of blue indicate a county has a larger number of thermostats; white indicates the county does not have matched TCC thermostat homes. As shown, adopters of Honeywell connected thermostats primarily lived in major urban areas of the United States, with the greatest presence in cities of the East Coast, West Coast, the Mountain West, and the Midwest.

Figure 2. Geographic Distribution of TCC Thermostat Homes

Source: Cadmus analysis of locations of TCC thermostat adopters.
Step 3: Estimate Models of Home Energy Use for Heating and Cooling

Cadmus estimated the parameters of econometric models of energy use for home space heating and cooling using matched RECS data. The models took the specifications indicated by Equation 1, and Cadmus estimated separate models for each Building America climate zone.\(^{13}\)

Estimation of Equation 1 required data about the number of hours of space heating and cooling and the average outside temperatures during heating and cooling for each RECS home. To obtain these data, Cadmus used hourly temperature data for 2009 from hundreds of National Oceanic and Atmospheric Administration U.S. weather stations. Cadmus calculated the number of space heating and cooling hours and average outside temperatures during the space heating and cooling seasons for each of the 41 unique reportable domain and climate zone combinations in the continental U.S.

The study estimated the number of space-heating hours as the annual number of hours with an average outside temperature below the home’s average heating thermostat set point. Similarly, the study estimated the length of the cooling season as the annual number of hours with an average outside temperature exceeding the home’s average cooling set point. This approach ensured the estimated length of each home’s heating and cooling seasons depended on its demand for space heating and cooling.

Estimating Equation 1 also required estimates of a home’s attic ceiling area and exterior wall area. Using assumptions about the ratio of a home’s length to width and ground floor to attic ceiling height, Cadmus estimated the attic ceiling area and exterior wall area of each home. The study verified the regression estimates were sufficiently robust to changes in these assumptions.

Cadmus then estimated Equation 1 by weighted least squares, with weights obtained from the CEM procedure. These weights controlled for differences between treatment and control groups in strata sizes (i.e., the number of matched observations). Cadmus estimated White standard errors to account for heteroskedasticity (i.e., non-constant variance of home space heating or space cooling energy use intensity).

For each climate zone, the estimated coefficients in the heating and cooling models were positive and statistically significant. As noted, these coefficients indicated energy-use intensities per degree of difference between the thermostat average temperature set point and the average outside temperature. Cadmus verified that, on average, the models yielded accurate predictions of energy use for homes in the analysis sample.

Using the regression results, Cadmus estimated the average energy savings as a percent of consumption from a home adjusting its thermostat setting downward (upward) by one degree during the heating

\(^{13}\) There are five major Building America climate zones: Hot-Dry/Mixed-Dry (covering the southwestern U.S. and southern California), Hot-Humid (covering the southeastern U.S. and parts of Texas), Marine (covering coastal Oregon, Washington, and northern California), Mixed-Humid (covering the humid and temperature regions of the Middle Atlantic, Lower Midwest, and upper South), and Very Cold/Cold (covering New England, the upper Midwest, and the upper West).
(cooling) season. The estimates applied to U.S. households with house sizes, incomes, locations, and climates similar to those of TCC thermostat adopters. This exercise did not indicate energy savings from connected thermostats, a calculation that first requires estimating the impact of connected thermostats on thermostat set points.

Figure 3 shows estimates of average energy savings from a 1°F change in thermostat average set points. The energy savings estimates assumed normal weather (TMY 2010).

Adjusting the temperature set point downward by an average of 1°F would save 5.7% of space heating energy use of a typical home. A home’s savings would depend on a number of factors, including the length of the heating and cooling season, the efficiency of space conditioning equipment, and the thermal efficiency of the home’s envelope. Similarly, for cooling, adjusting the thermostat upward by an average of 1°F would save 11.9% of space cooling energy use. Together, the adjustments would save 7.2% of the average home’s energy use for space conditioning.

Figure 3. Percent Energy Savings for Heating from 1°F Adjustment of Thermostat Setting

Notes: Results based on Cadmus analysis. See text for details.

Step 4: Determine the Effect of TCC Thermostats on Temperature Set Points
Cadmus estimated the average heating and cooling season thermostat set points for matched TCC thermostat homes and RECS homes.

This involved first estimating the set points in TCC thermostat homes as the average set point between December and March during the hours when the home had the space heating system switched to on.
The study limited the analysis to this period to remain consistent with the RECS, which asked respondents to report thermostat set points for heating “during winter.”

For cooling, Cadmus estimated thermostat average temperature set points in TCC thermostat homes as the average during the summer months of June, July, August, and September, with cooling systems switched to on. RECS asked respondents to report thermostat set points “during summer.”

Cadmus estimated the average set point in RECS homes using survey data about typical thermostat settings during the day when the home was occupied and unoccupied and at night as well as information about whether the home was typically occupied during the day.

For each region, Cadmus used a linear regression to estimate the mean difference in space heating or cooling set points between matched RECS and TCC thermostat homes. This regression accounted for any remaining differences in thermostat set points that could have been explained by the CEM matching variables. Linear regressions for home average thermostat set point took the following form:

\[
\text{Avg. t-stat set point}_i = g(\text{TCCHome}_i, \text{reportable domain}_i, \text{income}_i, \text{floor area}_i) \quad \text{(Equation 2)}
\]

Where:

\[
\text{Avg. t-stat set point}_i = \text{The average thermostat set point of home } i \text{ during the heating or cooling season.}
\]

\[
\text{TCCHome}_i = \text{An indicator variable for whether home } i \text{ has a TCC thermostat. This variable equals 1 if the home has a TCC thermostat and 0 if it is a RECS home.}
\]

\[
\text{Reportable domain}_i = \text{A vector of indicator variables for the different reportable domains (states) in the climate zone. The } j\text{th element of the vector equals 1 if home } i \text{ is in the } j\text{th reportable domain, } j = 1, 2, \ldots, J, \text{ and 0 otherwise.}
\]

\[
\text{Income}_i = \text{Household income for home } i. \text{ Income enters the regression as a third-degree polynomial.}
\]

\[
\text{Floor area}_i = \text{The floor area of the home. Floor area enters the regression as a third-degree polynomial.}
\]
The coefficient on TCCHome indicated the mean difference in temperature set points between TCC thermostat homes and RECS homes conditional on the other independent variables.\textsuperscript{14}

Cadmus estimated the models by OLS and clustered the standard errors on the reportable domain.

**Step 5: Estimate Energy Savings**

The final analysis step involved estimating space heating and cooling energy and energy cost savings from TCC thermostats. Cadmus used the following equation to estimate energy savings for a normal weather year:

\[ \text{TCC thermostat energy savings per home} = \Delta F \times s \times h \quad \text{(Equation 2)} \]

Where:

- \(\Delta F\) = regression-based estimate of the difference between matched TCC thermostat homes and RECS homes in average temperature set points
- \(s\) = regression-based estimate of energy savings per hour, per degree of setback for the average home
- \(h\) = heating (cooling) hours in a normal weather year

Calculating \(s\) — the energy savings (in kBTUs) per hour, per degree of setback — required evaluating Equation 1 for particular values of attic ceiling and exterior wall areas. Cadmus selected the average attic ceiling and the average exterior wall areas of the U.S. or region in the analysis sample for this calculation.

---

\textsuperscript{14} Readers may be concerned that this study compares self-reported thermostat set points in RECS homes to set points from thermostat user interface data. The important issue is not whether data come from different sources, but whether either source likely yields biased estimates of average thermostat set points. The TCC thermostats provide accurate data on thermostat set points, indicating that we can be confident in the quality of these data. RECS data are self-reported, raising the question of whether respondents accurately reported their thermostat set points. Cadmus found two studies that compared self-reported data with observed thermostat set points. Both are more than two decades old: Lutz and Wilcox (1990); and Gladhard et al. “Reported Versus Actual Thermostat Settings: A Management Perspective,” a Michigan State University working paper. Neither paper provided conclusive evidence that self-reported thermostat set points differ from or are less reliable than observed thermostat set points. Lutz and Wilcox collected data on self-reported and observed thermostat set points for approximately 30 new homes in California during the heating and cooling season and for different periods of the day. The authors found statistically significant differences in only three of eight periods. Gladhard et al. found differences in thermostat set points, but the analysis sample included only eight homes, a sample much too small for drawing conclusions. Both studies found respondents underestimated their average heating set points and overestimated their cooling set points, suggesting respondents used more energy than they believed. If this tendency applied to the U.S. population, it would indicate the RECS baseline is biased towards efficiency, and this study’s estimates of energy savings from connected thermostats may be too small and should be considered conservative.
Cadmus estimated the energy cost savings as:

\[ \text{TCC Thermostat energy cost savings} = p \times \text{TCC thermostat energy savings per home} \quad (\text{Equation 3}) \]

Where:

\[ p = \text{the average retail price per kBTU for energy used in heating or cooling} \]

Cadmus estimated \( p \) for heating using EIA data on 2014 residential retail prices for electricity, natural gas, and heating oil during the heating months of December, January, February, and March. The analysis determined \( p \) as a weighted average of these prices, with weights equal to each energy source’s share of total residential energy use in kBTUs. The analysis also determined \( p \) for cooling using 2014 EIA data on electricity prices during the cooling months of June, July, August, and September.
TCC Thermostat Energy Savings Estimates

This section presents estimates of TCC thermostat annual energy and energy cost savings for the United States and for U.S. census divisions, small regional groupings of states (and the District of Columbia). Cadmus reported savings for census divisions because TCC thermostat energy savings may differ from the average according to climate as well as to home and household characteristics. Homes and households within a census division often share similar climates and many energy use characteristics.

Cadmus estimated average energy savings per home for space heating and cooling as a function of the difference in average temperature set points between homes with and without TCC thermostats. The first section presents estimates of the differences in average thermostat set points, followed by estimates of TCC thermostat annual energy savings and energy cost savings.

**Differences in Thermostat Interior Temperature Set Points**

Figure 4 shows estimates of average set points during the heating season in matched Honeywell TCC thermostat homes and RECS homes. The estimates were based on analysis of thermostat set points for approximately 34,000 homes with TCC thermostats and 3,400 RECS homes without connected thermostats.

![Figure 4. Average Thermostat Temperature Set Points—Heating Season](image)

Note: TCC thermostat set points estimated for hours with heating systems switched to on, between December and March. All differences were statistically significant at the 5% level, except in the East South Central, Mountain-South, and West North Central census divisions. The census division abbreviations are: ENC=East North Central; ESC=East South Central; MA=Middle Atlantic; M-N =Mountain North; M-S=Mountain South; NE=New England; P=Pacific; SA=South Atlantic; WNC=West North Central; and WSC=West South Central.
Homes with TCC thermostats had lower average heating set points than homes without connected thermostats. As noted, the baseline was a blend of programmable and non-programmable thermostats. For the continental U.S., the average temperature set point in TCC homes was 66.3°F, about 1.4°F less than the average temperature set point in RECS baseline homes. This difference was statistically significant at the 5% level.

TCC thermostat homes had lower average set points during the heating season in all census divisions. The differences in set points ranged between -0.5°F (Pacific) to -2.4°F (South Atlantic). The differences were statistically significant at the 5% level, except in the East South Central, Mountain-South, and West North Central census divisions.

Figure 5 presents estimates of average set points during the cooling season for homes with and without connected thermostats. This does not include estimates for New England as not enough RECS homes in this climate zone reported using central air conditioning.

Notes: TCC thermostat set points estimated for hours with cooling system switched to on, between June and September. All differences were statistically significant at the 5% level. The census division abbreviations are: ENC=East North Central; ESC=East South Central; MA=Middle Atlantic; M-N =Mountain North; M-S=Mountain South; NE=New England; P=Pacific; SA=South Atlantic; WNC=West North Central; and WSC=West South Central.

Programmable thermostats were in the majority of matched baseline RECS homes. Programmable thermostats were in 78% of homes in the Hot-Dry/Mixed-Dry climate zone, 63% of homes in the Hot-Humid climate zone, 87% of homes in the Marine climate zone, 59% of homes in the Mixed-Humid climate zone, and 71% of homes in the Very Cold/Cold climate zone. To the extent that programmable thermostats yielded efficiency savings, the baseline would have largely incorporated these efficiency savings.
Homes with TCC thermostats had higher average cooling set points. Across all census divisions (except New England), the average temperature set point in matched TCC thermostat homes was 75.8°F, or 1.3°F greater than the average temperature set point in matched RECS homes. This difference was statistically significant at the 5% level.

In each census division, TCC thermostat homes had higher average cooling set points. Differences ranged from 1°F or less in the West North Central and Mountain-South to over 2°F in the East North Central, Mid-Atlantic, Mountain-North, and Pacific. All differences were statistically significant at the 5% level.

In summary, the comparison of thermostat set points suggests homes with TCC thermostats used less energy for space heating and cooling. Homes with TCC thermostats had lower average set points for space heating and higher average set points for space cooling than similar homes with programmable or nonprogrammable thermostats.

**Energy and Energy Cost Savings from TCC Thermostats**

As described in the methodology section, Cadmus estimated the space heating and space cooling energy savings as a function of the difference in average temperature set points between TCC thermostat and RECS homes. In addition, the estimate of the average energy savings per home depended on the following:

- The length of the heating and cooling seasons;
- The efficiency of space conditioning equipment; and
- The thermal efficiency of the home’s envelope.

For example, homes in the South Atlantic and East South Central had long cooling seasons and, with all else equal, would be expected to have the greatest cooling energy savings. Homes with less-efficient space conditioning equipment or poorly insulated exterior walls and attic ceilings would also be expected to experience greater energy savings.

Cadmus calculated energy savings assuming a normal weather year. Energy cost savings were estimated as a function of the state-specific 2014 residential retail price of energy.

As shown in Figure 6, the average U.S. home with a Honeywell connected thermostat reduced energy use 7.8% for space heating and 16.5% for space cooling during a normal weather year. Percentage energy savings were greater during the cooling season because the average impact of TCC thermostats (+1.3°F) constituted a larger percentage of the gradient between the outside temperature and the thermostat temperature set point.
Overall, energy savings for space conditioning from TCC thermostats were 9.1% during a normal weather year—an estimate much closer to that of the average space heating savings, as space heating accounted for approximately seven times as much energy use as space cooling (42% vs. 6%) in the average home. Estimates of energy savings are statistically significant at the 5% level. As space conditioning accounted for 40%–50% of energy use in a typical U.S. home, energy savings from adoption of TCC thermostats equaled about 3%–4% of home energy use.

Figure 7 shows average space heating and cooling energy cost savings for U.S. homes for a normal weather year. The average home with a TCC thermostat would save $45 per year in energy for space heating and $90 per year in energy for space cooling. Total energy cost savings from space heating and cooling would equal $135. These estimates were also statistically significant at the 5% level.
Figure 7. TCC Thermostat Annual Energy Cost Savings Per Home

Notes: Estimates of cost savings assume a normal weather year and 2014 energy prices. See the methodology section for estimation details. Error bars indicate 95% confidence intervals.

Comparison to Savings Estimates from First National Impact Study
As noted, Cadmus released an impact study based on analysis of user interface data for a smaller number of TCC thermostats (approximately 800) in October 2014. Figure 8 and Figure 9 compare the estimates of energy savings and energy cost savings from this study and the first study.
This study found greater energy savings for space heating, but slightly lower savings for space cooling. For all home space conditioning, this second study finds greater savings (9.2% vs. 6.7%). Nevertheless, the savings estimates from the two studies are relatively close and not statistically different at the 5% level. Differences between the studies may result from differences between analysis samples in locations, sizes, and incomes of TCC thermostat homes.
The first and second studies also produced fairly similar estimates of energy cost savings. This second study finds higher space heating energy cost savings; approximately equal space cooling energy cost savings; and greater overall cost savings. These differences, however, were not statistically significant at the 5% level.

**Regional Savings Estimates**

Figure 4 and Figure 5 indicate significant differences existed between census divisions in TCC thermostats’ impacts on average space heating and cooling set points. How did these differences affect regional energy savings?

Figure 10 and Figure 11 show estimates of TCC thermostat space heating and space cooling energy and energy cost savings for U.S. census divisions.

As shown in Figure 10, homes in the South Atlantic, West South Central, and New England census divisions had the greatest space heating energy savings and cost savings. Homes in the South Atlantic saved 17% of space heating energy use and about $78 in annual energy costs. Homes in the West South Central division saved about 14% of space heating energy use and $75 in annual energy costs. These two climate zones exhibited the highest average temperature set points and, thus, some of the greatest savings potential. TCC thermostat adopters in New England saved an average of $63 per home per year.

In contrast, despite having high space heating demand, homes in the East North Central and West North Central had relatively small—though still significant—energy and energy cost savings. In the East North
Central, the average TCC thermostat adopter saved 3% of space heating energy use and about $25 in annual energy costs.

The greatest contributing factor to differences in energy savings between census divisions was the reduction in average thermostat set points provided by TCC thermostats (though other factors, such as the length of the heating and cooling seasons, the thermal efficiency of the home’s envelope, and energy costs contributed). For example, Cadmus found small energy savings in the Mountain-South and Pacific divisions because, as shown in Figure 4, TCC thermostat homes and RECS homes had similar average heating set points.
Figure 10. TCC Thermostat Space Heating Energy and Cost Savings by Census Division

Source: Cadmus analysis. See text for details.

Figure 11. TCC Thermostat Space Cooling Energy and Cost Savings by Climate Zone

Source: Cadmus analysis. See text for details.
Figure 11 shows estimates of the average space cooling energy savings per home for U.S. census divisions. TCC thermostat adopters in regions with long and warm summers achieved the greatest space cooling energy savings. In the South Atlantic, East South Central, and West South Central divisions, TCC thermostats saved an average of $112, $106, and $134 per home, respectively, during a normal weather year. Homes in other census divisions had smaller cost savings but saved significantly more energy as a percent of consumption because their energy use for air conditioning was small.

Figure 12 shows estimates of the combined average space heating and space cooling energy savings per home for U.S. census divisions. The percent energy savings ranged from 3% in the West North Central division to 18% in the South Atlantic division. In the other divisions, space conditioning energy savings ranged between 6 and 10%. TCC thermostat adopters in the Middle Atlantic, South Atlantic, and West South Central regions had high demand for both space heating and cooling and therefore the largest energy cost savings.

**Cost-Effectiveness of TCC Thermostat Adoption**

Many homeowners considering purchasing a Honeywell TCC thermostat will want to compare expected annual energy cost savings with the thermostat’s incremental cost. This comparison will also interest energy efficiency policymakers, as many jurisdictions require energy efficiency measures to pass the Participant Cost Test, a comparison of the utility customer’s benefits and costs of installing a measure.
Table 2 shows for each census division the TCC thermostat average annual energy cost savings per home from Figure 12 and the approximate time to achieve energy cost savings equal to the incremental cost of a TCC thermostat. To calculate the payback period, Cadmus assumed an incremental cost for a connected thermostats of $100 and discounted energy cost savings at an annual rate of 8%.

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Annual Energy Cost Savings Per Home</th>
<th>Approximate Payback Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>East North Central (IL, IN, MI, OH, WI)</td>
<td>$100</td>
<td>≈ 1 year</td>
</tr>
<tr>
<td>East South Central (AL, KY, MS, TN)</td>
<td>$125</td>
<td>≈ 1 year</td>
</tr>
<tr>
<td>Mid-Atlantic (NJ, NY, PA)</td>
<td>$142</td>
<td>&lt;1 year</td>
</tr>
<tr>
<td>Mountain North (CO, ID, MT, UT, WY)</td>
<td>$171</td>
<td>&lt;1 year</td>
</tr>
<tr>
<td>Mountain South (AZ, NM, NV)</td>
<td>$92</td>
<td>≈ 1 year</td>
</tr>
<tr>
<td>New England (CT, MA, ME, NH, RI, VT)</td>
<td>$63*</td>
<td>≈ 2 years</td>
</tr>
<tr>
<td>Pacific (CA, OR, WA)</td>
<td>$99</td>
<td>≈ 1 year</td>
</tr>
<tr>
<td>South Atlantic (DC, DE, FL, GA, MD, NC, SC, VA, WV)</td>
<td>$190</td>
<td>&lt;1 year</td>
</tr>
<tr>
<td>West North Central (IA, KS, MN, MO, ND, NE, SD)</td>
<td>$49</td>
<td>≈ 2 years</td>
</tr>
<tr>
<td>West South Central (AR, LA, OK, TX)</td>
<td>$197</td>
<td>&lt;1 year</td>
</tr>
<tr>
<td>All climate zones</td>
<td>$135</td>
<td>&lt;1 years</td>
</tr>
</tbody>
</table>

Notes: The payback period was estimated as the minimum number of years required to achieve average energy cost savings equal to the incremental cost of a TCC thermostat. Annual energy cost savings equaled the sum of space heating and cooling energy cost savings. Analysis assumed the discount rate equaled 8%, the incremental cost of connected thermostat relative to a standard programmable thermostat equaled $100, and future energy prices do not change from 2014 levels.

*Includes only space heating energy cost savings because New England’s space cooling energy savings were not estimated. See text.

Depending on the census division, average annual energy cost savings per home (i.e., the sum of heating and cooling energy cost savings) ranged from about $50 to $175, and the payback periods for TCC thermostats ranged from less than one year to approximately two years. In most regions, the payback period was one year or less. As discussed, homes in the South Atlantic, West South Central, and Mid-Atlantic regions had the greatest annual energy cost savings and thus the shortest payback periods (less than one year). As energy cost savings were smaller in the West North Central and Mountain South divisions, the average home would have to wait longer to recover the thermostat’s incremental cost. Across the U.S., average annual energy cost savings were $135 per home and the average payback period was less than one year.

In summary, these results suggest adoption of TCC thermostats has been cost-effective for many adopters.

Cost of Saved Energy for Utility Connected Thermostat Efficiency Programs
This section presents estimates of a utility’s levelized cost of saved energy for a direct-install efficiency program involving Honeywell TCC thermostats. Utilities use levelized costs to make comparisons between different energy efficiency and generation resources with varying lifespans. To estimate the levelized cost of saved energy, Cadmus used the TCC thermostat annual energy savings estimates,
shown in Figure 10 and Figure 11, and assumptions about the costs of administering a direct-install efficiency program, average thermostat life, and the utility discount rate.\textsuperscript{16}

Cadmus estimated the cost of saved energy under low-cost and high-cost scenarios about a utility’s average program deployment cost per thermostat. The high-costs scenario would correspond to a smaller program or one with more expensive program design, direct marketing, recruitment, hardware acquisition, contractor training, or installation costs. Cadmus assumes a cost of $400 per thermostat for the low-costs scenario and $700 per thermostat for the high-costs scenario. All utility costs are incurred in the first program year.

Table 3 shows estimates by census division and for the United States of a utility’s levelized cost of kWh savings from space cooling and a utility’s levelized cost of therm savings from space heating. Cadmus estimated separate costs of saved energy for space heating and cooling and did not account for a utility using thermostats to save energy for both end-uses.

\textsuperscript{16} Cadmus estimated the levelized cost of saved energy for the TCC thermostat program as follows:

\[
\text{levelized cost of saved energy} = \frac{\text{Annual Program Cost} \times \text{Capital Recovery Factor}}{\text{Annual energy savings}}
\]

where: \[
\text{capital recovery factor} = \frac{\delta \times (1+\delta)^m}{(1+\delta)^m - 1}
\]

\(\delta\) denotes the utility’s discount rate and \(m\) is the expected measure life.

Cadmus assumed a utility discount rate of 6\% and average lifetime of a TCC thermostat of 10 years.
## Table 3. Levelized Cost of Saved Energy for Utility TCC Thermostat Efficiency Programs

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Space Cooling Energy Savings Levelized Costs ($/kWh)</th>
<th>Space Heating Energy Savings Levelized Costs ($/therm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Program Costs Scenario</td>
<td>High Program Costs Scenario</td>
<td>Low Program Costs Scenario</td>
</tr>
<tr>
<td>East North Central (IL, IN, MI, OH, WI)</td>
<td>$0.11</td>
<td>$0.19</td>
</tr>
<tr>
<td>East South Central (AL, KY, MS, TN)</td>
<td>$0.07</td>
<td>$0.13</td>
</tr>
<tr>
<td>Mid-Atlantic (NJ, NY, PA)</td>
<td>$0.08</td>
<td>$0.15</td>
</tr>
<tr>
<td>Mountain North (CO, ID, MT, UT, WY)</td>
<td>$0.07</td>
<td>$0.12</td>
</tr>
<tr>
<td>Mountain South (AZ, NM, NV)</td>
<td>$0.10</td>
<td>$0.17</td>
</tr>
<tr>
<td>New England (CT, MA, ME, NH, RI, VT)</td>
<td>$0.15</td>
<td>$0.26</td>
</tr>
<tr>
<td>Pacific (CA, OR, WA)</td>
<td>$0.09</td>
<td>$0.16</td>
</tr>
<tr>
<td>South Atlantic (DC, DE, FL, GA, MD, NC, SC, VA, WV)</td>
<td>$0.07</td>
<td>$0.13</td>
</tr>
<tr>
<td>West North Central (IA, KS, MN, MO, ND, NE, SD)</td>
<td>$0.24</td>
<td>$0.42</td>
</tr>
<tr>
<td>West South Central (AR, LA, OK, TX)</td>
<td>$0.06</td>
<td>$0.11</td>
</tr>
<tr>
<td>All Census Divisions</td>
<td>$0.09</td>
<td>$0.15</td>
</tr>
</tbody>
</table>

Notes: See the text for details about estimation of levelized cost of saved energy. Cadmus assumed TCC thermostats had an average life of 10 years. The low program costs scenario assumed a program average deployment cost $400 per thermostat. The high-cost scenario assumed a program average deployment cost $700 per thermostat.

For the U.S., the average utility’s levelized cost of space cooling savings would be $0.09/kWh for the low program costs scenario and $0.15/kWh for the high program costs scenario. The low program levelized cost of saved energy would exceed the median levelized cost of saved energy ($0.06/kWh) for utility residential whole-home or direct-install programs in the U.S. (LBNL, 2014). However, under the low program costs scenario, utilities in the East South Central, Mountain-North, South Atlantic, and West South Central census divisions would have average levelized costs only $0.01 or $0.02 greater than the national median.

For the U.S., the average utility’s levelized cost of space heating energy savings would be $1.65/therm for the low program costs scenario and $2.88/therm for the high program costs scenario. This levelized cost and those for each census division exceed the national average levelized cost of energy savings for residential gas efficiency programs of $0.32/therm (LBNL, 2014).

### How The Paper’s Results Should Be Used

As connected thermostats constitute a new product offering, relatively little information still exists about their expected energy savings. This national study helps fill this gap by estimating energy and energy cost savings that utilities across the United States can expect from Honeywell connected thermostats.

---

17 LBNL based this estimate on an analysis of 19 residential whole-home/direct-install utility electricity efficiency programs. See LBNL (2014), p. 34.
This study primarily is intended to assist utilities and regulators with efficiency program planning, and is not intended as a substitute for carefully designed evaluation field studies of energy savings from connected thermostats. Utilities will have to conduct their own EM&V to verify the expected savings.

Finally, this study considers only space heating and space cooling energy savings, and does not consider utilities’ potential benefits of using Honeywell TCC thermostats to manage residential space-conditioning loads to obtain peak-demand savings.
Conclusions

Connected thermostats can help homeowners better manage energy use for space conditioning. Mobile connectivity and programmability reduces the cost of controlling home space heating and cooling and can help users better maintain their preferred interior temperatures. This reduction in the cost of control also may also better align home space conditioning with occupancy and therefore yield energy savings.

In this study, Cadmus estimated energy savings from Honeywell TCC thermostats. This required analyzing UI data for over 30,000 homes with TCC thermostats and comparing average temperature set points of TCC thermostats to the self-reported thermostat set points of households in the 2009 RECS with non-connected thermostats. Cadmus then estimated energy savings for space conditioning as a function of the difference in average temperature set points between TCC thermostat homes and RECS homes.

Summary of Main Findings

The average adopter of Honeywell TCC thermostats saved significant energy for space heating and cooling, and adoption proved highly cost-effective for many homes.

The analysis resulted in the following specific findings:

- Homes with Honeywell TCC thermostats had lower average set points during winter (-1.4°F) and higher average set points during summer (+1.3°F) than homes with programmable or nonprogrammable thermostats.
- On average, Honeywell TCC thermostats saved about 8% of energy use for home space heating and 17% of energy use for home space cooling during a normal weather year. In total, TCC thermostats saved about 9% of annual energy use for space heating and cooling.
- Honeywell TCC thermostats saved about $45 per home per year in space heating energy costs and $90 per home per year in space cooling energy costs during a normal weather year. Total energy cost savings were $135 per home per year.
- Energy and energy cost savings varied significantly between regions. Homes with long space heating and space cooling seasons saved the most energy and realized the greatest energy cost savings.
- Homes in the Mid-Atlantic, South Atlantic, and West South Central census divisions achieved the greatest space conditioning energy savings. Estimated combined space-heating energy cost savings and space cooling cost savings in these regions were, respectively, $142, $190, and $197 per home per year.
- Adoption of TCC thermostats proved cost-effective for many homes. In most census divisions, the TCC thermostat annual energy cost savings exceeded or just equaled the incremental costs of TCC thermostats. Adopters achieved a positive return on their investments after approximately one year.
The levelized cost of space cooling energy savings for a utility direct-install program featuring Honeywell TCC thermostats would be $0.09 per kWh under a low-cost program scenario and $0.15 per kWh under a high-cost program scenario, which both exceed the median levelized cost of saved electricity ($0.06/kWh) for utility residential whole-home or direct-install programs in the United States (LBNL, 2014). However, utilities in the East South Central, Mountain-North, South Atlantic, and West South Central census divisions would have levelized costs only slightly greater than the national median.
References


