Work Paper SW13XX###
Revision

Program Administrator: Southern California Edison

Prepared by Southern California Edison and Nest Labs

Residential Smart Thermostat

For Work Paper Reviewer Use Only

List all major comments that occurred during the review. This table may only be removed during management review.

Major Comment	Reviewer Name	Date	Outcome/Resolution

September 2, 2016

AT-A-GLANCE SUMMARY

Measure Codes	TBD
Measure Description	Residential Smart Thermostat
Base Case Description	Setback Programmable Thermostats or Non-Programmable Thermostats
Units	1 unit = 1 Smart Thermostat
Energy Savings	Refer to Attachment
Full Measure Cost ($/unit)	$219.17
Incremental Measure Cost ($/unit)	$125.05
Effective Useful Life	EUL: 11 years RUL: 3.66 years DEER EUL ID: (HV-ProgTstat)
Measure Installation Type	Early Retirement (ER)
Net-to-Gross Ratio	0.85 (DEER NTG ID: CA Emerging Technology) Refer to description below for details
Important Comments	This work paper has a complementary Ex Ante Database data set that will be provided in a separate submission to the California Public Utilities Commission (CPUC).

September 2, 2016

REVISION HISTORY

Rev	Date	Author	Summary of Changes
0	9/2/2016	Jeff Gleeson (Nest), Aaron Berndt (Nest), Andres Fergadiotti (SCE)	New workpaper, first version

COMMISSION STAFF AND CAL TF COMMENTS

Rev	Party	Submittal Date	Comment Date	Comments	WP Developer Response

Cal TF website: http://www.caltf.org/

September 2, 2016

SECTION 1. GENERAL MEASURE & BASELINE DATA

1.1 MEASURE DESCRIPTION & BACKGROUND

A **Smart Thermostat** is a device that controls heating, ventilation, and air-conditioning (HVAC) equipment to regulate the temperature of the room or space in which it is installed, has the ability to make smart and automated adjustments for the customer to drive energy savings, and has the ability to communicate with sources external to the HVAC system. For connection, the Smart Thermostat may rely on a home area network (e.g. Wi-Fi) and an internet connection that is independent of the Smart Thermostat.

This workpaper (wp) details the installation of a Residential Smart Thermostat. This measure characterizes the household heating and cooling energy savings from the installation of a Smart Thermostat. Smart Thermostats reduce energy consumption using a combination of features described in Section 1.2 Technical Description.

Base, Standard, and Measure Cases

Case	Description of Typical Scenario
Measure	Residential Smart Thermostat with two way communication and automatic scheduling capabilities
Existing Condition	Setback Programmable Thermostats or Non-Programmable Thermostats

Measures and Codes

Measure Codes				Measure Name
SCG	SDG&E	SCE	PG&E	
TBD	TBD	TBD	TBD	Residential Smart Thermostat

Eligibility Requirements:

- A qualified Wi-Fi thermostat per guidelines described below
- Customer segment: residential
- Must use the thermostat to control both heating and cooling equipment supplied by fuels provided by the utility paying the end-customer incentive
    a. Eligible heating equipment: gas forced-air furnace, electric forced-air furnace, heat pump
    b. Eligible cooling equipment: central air conditioning

Implementation and Installation Requirements:

- **Climate Zones:** All 16 California Climate Zones are eligible
- **Building Types:** Single Family Residential Building Types

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1.2 Technical Description

Smart thermostats are enhanced by data gathering and analytics functionalities, which enables them to use a variety of methods to optimize HVAC settings for efficient and automated energy consumption. Specifically, a smart thermostat is defined as a thermostat that is compatible with the participant's HVAC system, and has

- Two-way communication,
- Occupancy detection (through the use of occupancy sensors, geofencing, etc.), and
- At least two of the features in Table 1-2.

Explanations of how these features save energy is provided in Table 1-1

Table 1-1. Smart Thermostat Features[1]

Feature	Feature Description
Schedule learning	Thermostat learns occupant patterns with little to no effort from the customer.
Heat pump auxiliary heat optimization	Thermostat optimizes the use of the refrigerant heating cycle in preference to auxiliary heat, while still enabling the home to achieve a comfortable setpoint.
Upstaging / downstaging optimization	Thermostat optimizes the use of the lowest and most efficient stage of heating or cooling in preference of the higher capacity stage, while still enabling the home to achieve a comfortable setpoint.
Humidity control	Thermostat uses a humidity sensor to optimize HVAC operation.
Weather-enabled optimization	Thermostat uses weather predictions and weather data to optimize the HVAC system.
Free cooling / economizer capability	Thermostat recognizes the indoor/outdoor temperature difference and uses the outside air instead of the air conditioner or heating system to cool or heat the home when possible.

[1] In addition to the features listed, smart thermostats typically have easy-to-use setpoint scheduling, fan dissipation, and behavioral features. Fan dissipation enables compressors or heaters to turn off early, while the fan continues to run and condition the home with air in the duct system that is still cold or warm. Also, smart

thermostats often have behavioral features such as default or recommended setback temperatures, and energy scorecards.

1.3 Installation Types and Delivery Mechanisms

Installation Type Descriptions

Installation Type	Savings		Life	
	1st Baseline (BL)	2nd BL	1st BL	2nd BL
Retrofit or Early Replacement (RET/ER)	Above Customer Existing	Above Code or Standard	RUL	EUL-RUL

A delivery mechanism is a delivery method paired with an incentive method. Delivery mechanisms are used by programs to obtain program participation and energy savings.

Delivery Method Descriptions

Delivery Method	Description
Financial Support	The program motivates customers, through financial incentives such as rebates or low interest loans, to implement energy efficient measures or projects.

Incentive Method Descriptions

Incentive Method	Description
Downstream Incentive	The customer installs qualifying energy efficient equipment and submits an incentive application to the utility program. Upon application approval, the utility program pays an incentive to the customer. Such an incentive may be deemed or customized.

1.4 Measure Parameters

1.4.1 DEER Data

DEER Difference Summary

DEER Item	Used for Workpaper?
Modified DEER methodology	No
Scaled DEER measure	No
DEER Base Case	See details below for description of the RASS Base Case Calibration Factor, which leverages the same data used to create the DEER programmable thermostat base case
DEER Measure Case	No
DEER Building Types	No
DEER Operating Hours	No
DEER eQUEST Prototypes	No
DEER Version	-
Reason for Deviation from DEER	The DEER 2016 database does not contain an updated measure for Smart Thermostats.
DEER Measure IDs Used	-

Net-to-Gross Ratio

The Net-to-Gross (NTG) Ratio for this smart thermostat measure is 0.85, as it is categorized as an emerging technology in California's IOU energy programs. These devices have significant energy savings potential but have not yet achieved sufficient market share, making them under-utilized despite being commercially available.[1] The discussion below of market penetration in the Effective and Remaining Useful Life sections below provides additional relevant market insights.

This ET NTG value of 0.85 for smart thermostats aligns with prior Commission direction stating that measures introduced to utility program portfolios as a direct result of Emerging Technology Program activities be assigned a 0.85 NTG.[2] A series of market research studies[3] by the IOU teams, combined with emerging technology assessments of hardware and software, have led to this first iteration of the smart thermostat energy efficiency measure.

This ratio is further substantiated by the table below that shows Net-to-Gross Ratio values from recent smart thermostat studies in other jurisdictions throughout the U.S. that have recently implemented smart thermostat programs.

Because smart thermostats can deliver energy savings alongside demand response or Time of Use load management, it is important that the NTG Ratio for this measure be assessed in an integrated manner that is consistent with the goals of AB793, California's Long Term Strategic Energy Efficiency Plan, and California's long stated goals for integrated demand side management. These strategic drivers encourage the adoption of this type of technology - which can deliver EE and DR - to encourage the integration of demand side programs to achieve maximum savings and load management benefit, avoid duplicative efforts, reducing transaction costs, and reducing customer confusion.

With Bring Your Own Device (BYOD) demand response programs underway or launching soon in California, it is likely that customers will receive EE and DR incentive dollars for purchasing, installing, and DR enrollment of their smart thermostat. Customers look at the total incentive amount available to them, rather than delineating the utility program funding source, when considering a purchase of a smart thermostat. A larger combined incentive should be seen as a success for CA customers and should

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[1] Definition of Emerging Technologies from Energy Efficiency Policy Manual, ver. 5.0

[2] From D.12-05-015 *"We also agree with comments regarding Net-to-Gross values to use for measures added to the utility portfolios as a direct result of Emerging Technology Program activities (or Emerging Technologies measures). We direct Commission Staff to assign a new Net-to-Gross category for Emerging Technology measures with a default Net-to-Gross value of 0.85. The existing non-DEER measure submission process shall also cover Emerging Technology measures, and the utilities may request, in their non-DEER Emerging Technologies measure workpaper submissions, that measure be assigned a Net-to-Gross value at or above the 0.85 default value."*

[3] *Residential Programmable Communicating Thermostat Customer Satisfaction Survey*, SCE, 2006. *Residential Programmable Communicating Thermostat Customer Satisfaction Survey - Phase 2,* SCE, 2007.
Assessment of Programmable Communicating Thermostats: Technology, Costs and Required, Functionality, SCE, 2005.

be encouraged. Assigning an NTG in a fair and integrated manner properly captures the full program impact on customer adoption of the technology, and encourages IDSM.

NTG Values From Recent Studies

Study	NTG Value
Commonwealth Edison	0.96(5)
Illinois Technical Reference Manual	1.0(6)
Enbridge Gas DSM Plan	0.96(7)
Vectren	1.0(8)
CA Emerging Technology	0.85

In assessing all of these NTG values, 0.85 NTG is a valid starting point, while potentially even being a bit conservative, considering the combined EE/DR incentive level. A rebate/incentive value around $100 has shown to be very effective in getting new customers to adopt the technology that they have otherwise been waiting on due to cost. Choosing a NTG of 0.85 versus something closer to 1, allows for a decision to be made prior to all BYO DR Program elements are finalized/tested for some of the IOU's.

The relevant NTG values for the measures in this work paper are in the table below.

NTGR ID	Description	Sector	BldgType	Measure Delivery	NTGR
TBD	Smart Thermostat	Res	Any	Any	0.85

Spillage Rate

Spillage rates are not tracked in wps. Spillage rates are tracked in an external document, which will be supplied to the Commission Staff.

Installation Rate

The installation rate (IR) value was obtained using the DEER 2016, READI v2.4.3 tool. The relevant IR value for this wp measure is shown in the **Table 8**.

Table 8. Gross Savings Installation Adjustment Rate

GSIA ID	Description	Sector	BldgType	ProgDelivID	GSIAValue
Def-GSIA	Default GSIA values	Any	Any	Any	1

Effective and Remaining Useful Life

Standard/Code technology After RUL:

The standard/code technology before and after the RUL are the same for this measure (e.g., setback thermostat) because smart thermostat technology is so new, and in such an early stage of market adoption (see research summary below). It is worth noting that the definition of smart thermostats, for the purpose of this work paper, only includes those devices that provide enough software intelligence, combined with hardware features, to help customers automatically save energy. This definition very purposefully does not include those thermostats that are simply *connected* to the internet. It is tempting to assume that *smart* thermostats are close to being a standard technology given the volume of products and discussion surrounding *connected* thermostats.

Here is the research summarizing the early stages of adoption of the smart thermostats:

- Market penetration for Smart Thermostats, while growing each year, remains on the order of magnitude that places it in the early-adopter stage of the technology adoption cycle. Research by Berg Insights estimates that smart thermostats were installed in 4.5 million North American homes as of 2015(1). Given the total number of households in the US - close to 125 million - this single-digit adoption percentage shows that the market is still predominantly comprised of early adopters, and that it will take many years for the technology to become standard.
- Indeed, a report by Business Insider found that "the US smart home market as a whole is in the 'chasm' of the tech adoption curve..."(3)
- A report by Parks Associates found the market penetration, measured by the adoption of smart-home energy management technologies (which includes smart thermostats), to be on the order of 7% of all U.S. broadband households(2). It is worth noting that this includes additional smart home technology, not just smart thermostats.
- The Business Insider research, and an additional report by Parks Associates(4), found that high up-front product costs and low overall familiarity are two significant barriers to adoption.

Based on the state of the market analysis indicating very low market adoption, the RUL was set to 11 years to account for the fact that the market is still many years away from considering smart thermostats as the standard technology. Indeed, this was a main driver for AB793 legislation, which requires the utility programs to promote this type of technology to drive wider adoption.

EUL ID	Description	Sector	UseCategory	EUL (Years)	RUL (Years)
TBD	Smart Thermostats	Res	HVAC	11	3.66

First Baseline / Second Baseline:
As mentioned above, the savings estimates before and after the RUL are the same for this measure. The baseline adjustments outlined in Section 2.5 below present a conservative estimate for the 1st baseline. We assumed that that 1st baseline technology is either a manual or programmable thermostat with a flat schedule, and we then adjusted our savings estimates downward to account for how much more efficient Californians are compared to a flat schedule (see RASS baseline calibration factor discussion in Section 2.5).

The 2nd baseline would be programmable thermostats, which are standard in the marketplace, but we decided not to consider this our 2nd baseline, as that would have increased our savings estimates for the 2nd baseline time period. This would have increased our savings because it is documented (12) that programmable thermostats actually increase energy usage over manual thermostats, and therefore would have increased our savings estimates for the 2nd baseline time period. This approach aligns with the guidance to provide reasonable and conservative estimates.

1.4.2 Codes and Standards Analysis

This measure falls under the jurisdiction of Title 24 as listed in Table 10. Smart Thermostats have the capability to respond to a demand response signal, and therefore; exceed the functionality of thermostats that meet current 2013 Title-24 standards.

Table 10. Code Summary

Code	Reference	Effective Dates
Title 20 (2014)	N/A	N/A
Title 24 (2013)	Title 24, part 6 Section 110 Thermostats	July 1, 2014

Title 20: This measure does not fall under Title 20 of the California Code of Regulations

Title 24: Thermostats do fall under Title 24 of the California Code of Regulations, but smart thermostats discussed in this work paper do not. Title 24, part 6 states[i]:

> **Section 110**
>
> **Thermostats.** All unitary heating or cooling systems, including heat pumps, not controlled by a central energy management control system (EMCS) shall have a setback thermostat.
>
> **1. Setback Capabilities.** All thermostats shall have a clock mechanism that allows the building occupant to Program the temperature set points for at least four periods within 24 hours. Thermostats for heat pumps shall meet the requirements of Section 110.2(b). Space-conditioning systems shall be installed with controls that comply with the applicable requirements of Subsections (a) through (i).
>
> **Section 120**
>
> **Thermostatic Controls for Each Zone.** The supply of heating and cooling energy to each space-conditioning zone or dwelling unit shall be controlled by an individual thermostatic control

that responds to temperature within the zone and that meets the applicable requirements of Section 120.2(b).

EXCEPTION to Section 120.2(a): An independent perimeter heating or cooling system may serve more than one zone without individual thermostatic controls if:
1. All zones are also served by an interior cooling system;
2. The perimeter system is designed solely to offset envelope heat losses or gains;
3. The perimeter system has at least one thermostatic control for each building orientation of 50 feet or more; and
4. The perimeter system is controlled by at least one thermostat located in one of the zones served by the system.

(b) Criteria for Zonal Thermostatic Controls. The individual thermostatic controls required by Section 120.2(a) shall meet the following requirements as applicable:
1. Where used to control comfort heating, the thermostatic controls shall be capable of being set, locally or remotely, down to 55°F or lower.
2. Where used to control comfort cooling, the thermostatic controls shall be capable of being set, locally or remotely, up to 85°F or higher.
3. Where used to control both comfort heating and comfort cooling, the thermostatic controls shall meet Items 1 and 2 and shall be capable of providing a temperature range or dead band of at least 5°F within which the supply of heating and cooling energy to the zone is shut off or reduced to a minimum.

EXCEPTION to Section 120.2(b)3: Systems with thermostats that require manual changeover between heating and cooling modes.
4. Thermostatic controls for all unitary single zone, air conditioners, heat pumps, and furnaces, shall comply with the requirements of Section 110.2(c) and Reference Joint Appendix JA5 or, if equipped with DDC to the Zone level, with the Automatic Demand Shed Controls of Section 120.2(h).

Appendix JA5 - Technical Specifications For Occupant Controlled Smart Thermostats
The Occupant Controlled Smart Thermostat (OCST)2 shall be self- certified by the manufacturer to the Energy Commission to meet the requirements described in this section.

This document provides a high level technical specification for an OCST. All OCSTs shall comply with the
specifications set forth in this document or a specification approved by the Executive Director.

JA5.2 Required Functional Resources

JA5.2.1 Setback Capabilities
All OCSTs shall meet the requirements of Section 110.2(c). Thermostats for heat pumps shall lso meet the requirements of Section 110.2(b).

JA5.2.2 Communication Capabilities
OCSTs shall include communication capabilities enabled through either:

(a) At least one expansion port which will allow for the installation of a removable module containing a radio or physical connection port to enable communication; or

(b) Onboard communication device(s)

Shut-off and Reset Controls for Space-conditioning Systems. Each space-conditioning system shall be installed with controls that comply with the following:

1. The control shall be capable of automatically shutting off the system during periods of nonuse and shall have:
A. An automatic time switch control device complying with Section 110.9, with an accessible manual override that allows operation of the system for up to 4 hours; or
B. An occupancy sensor; or
C. A 4-hour timer that can be manually operated.

EXCEPTION to Section 120.2(e)1: Mechanical systems serving retail stores and associated malls, restaurants, grocery stores, churches, and theaters equipped with 7-day programmable timers.

2. The control shall automatically restart and temporarily operate the system as required to maintain:
A. A setback heating thermostat set point if the system provides mechanical heating; and

EXCEPTION to Section 120.2(e)2A: Thermostat setback controls are not required in nonresidential buildings in areas where the Winter Median of Extremes outdoor air temperature determined in accordance with Section 140.4(b)4 is greater than 32°F.

B. A setup cooling thermostat set point if the system provides mechanical cooling.

EXCEPTION to Section 120.2(e)2B: Thermostat setup controls are not required in nonresidential buildings in areas where the Summer Design Dry Bulb 0.5 percent temperature determined in accordance with Section 140.4(b)4 is less than 100°F.

Federal Standards: These measures do not fall under Federal DOE or EPA Energy Regulations.

Note that the applicable codes and standards for these measures dictate only that the thermostats be capable of shutting systems off and adjusting temperature set points during unoccupied hours. There are no requirements to actually shut down systems during unoccupied hours, or to make any specific unoccupied temperature set point adjustments

[i] Appendix H – 2013 Building Energy Efficiency Standards, Section 110.2

1.5 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information

Relevant smart thermostat studies that have been reviewed for this work paper.

1.5.1 Nest - Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results

- Nest Labs
- Completed: February, 2015
- Market Covered: Nationwide
- Techniques used: Billing analysis
- Relevance to and impacts on this work paper: corroborates savings quantified through EPA analysis

1.5.2 Energy Trust of Oregon Heat Pump Control Pilot Evaluation

- Prepared for Energy Trust of Oregon Prepared by Apex Analytics LLC
- Completed: October, 2014
- Market Covered: state of Oregon
- Techniques used: Billing analysis and surveys
- Relevance to and impacts on this work paper: additional support showing savings with smart thermostats

1.5.3 Evaluation of the 2013–2014 Programmable and Smart Thermostat Program

- Prepared for Vectren Corporation by The Cadmus Group
- Completed: January, 2015
- Market Covered: Central Indiana
- Techniques used: Billing analysis with some onsite data collection
- Relevance to and impacts on this work paper: additional support showing savings with smart thermostats

1.5.4 Evaluation of the 2013–2014 Programmable and Smart Thermostat Program

- Prepared for Northern Indiana Public Service Company by The Cadmus Group
- Completed: January, 2015
- Market Covered: Northern Indiana
- Techniques used: Billing analysis with some onsite data collection
- Relevance to and impacts on this work paper: additional support showing savings with smart thermostats

1.5.5 CPS Energy Nest Pilot Evaluation FY2015 - FINAL

- Prepared for CPS Energy by Nexant
- Completed: November, 2014
- Market Covered: Greater San Antonio, Texas area
- Techniques used: RCT billing analysis
- Relevance to and impacts on this work paper: additional support showing savings with smart thermostats

1.5.6 Evaluation of the Space Heating and Cooling Energy Savings of Smart Thermostats in a Hot-Humid Climate using Long-term Data

- D. Parker, K. Sutherland, D. Chasar Florida Solar Energy Center
- Completed: June, 2016
- Market Covered: Florida
- Techniques used: Pre-Post Analysis
- Relevance to and impacts on this work paper: additional support showing savings with smart thermostats

1.5.7 Demand Response Technology Evaluation of AutoDR Programmable Communicating Thermostats

- Design & Engineering Services, Southern California Edison
- Completed: December, 2012
- Market Covered: SCE Territory
- Techniques used: Field measurements to evaluate the Demand Response (DR) capabilities of Programmable Communicating Thermostats (PCTs) leveraging Open Automated Demand Response (OpenADR).
- Relevance to and impacts on this work paper: prior CA thermostat study

1.5.8 Residential Programmable Communicating Thermostat Customer Satisfaction Survey

- Design & Engineering Services, Southern California Edison
- Completed: March, 2006
- Market Covered: SCE Territory

- Techniques used: This report summarizes the responses of residential customers to a Programmable Communicating Thermostat (PCT) installed in their home to control their heating, ventilation, and air conditioning (HVAC) systems.
- Relevance to and impacts on this work paper: prior CA thermostat study

1.5.9 Impact Of PCTs On Demand Response – PHASE II

- Design & Engineering Services, Southern California Edison
- Completed: April, 2007
- Market Covered: SCE Territory
- Techniques used: This project analyzes the potential electricity demand response of small commercial HVAC systems and residential split air-conditioners due to the use of programmable communicating thermostats (PCTs).
- Relevance to and impacts on this work paper: prior CA thermostat study

1.5.10 Assessment of Programmable Communicating Thermostats: Technology, Costs and Required Functionality

- Design & Engineering Services, Southern California Edison
- Completed: September, 2005
- Market Covered: SCE Territory
- Techniques used: This document characterizes the attributes of existing and potential programmable communicating thermostats (PCTs), assesses utility program experience, PCT hardware, installation, and communication-related costs.
- Relevance to and impacts on this work paper: prior CA thermostat study

1.5.11 Residential Programmable Communicating Thermostat Customer Satisfaction Survey

- Design & Engineering Services, Southern California Edison
- Completed: March, 2007
- Market Covered: SCE Territory
- Techniques used: This report summarizes the survey responses of residential customers who were selected to participate in a test of a Programmable Communicating Thermostat (PCT) installed in their home to control their heating, ventilation, and air conditioning (HVAC) systems.
- Relevance to and impacts on this work paper: prior CA thermostat study

1.6 Data Quality and Future Data Needs

The analysis herein is based on more than 13 million days of data from more than 100,000 Nest Learning Thermostats across California and includes savings estimates by climate zone for both cooling and heating HVAC consumption (as well as electric savings from reduced furnace fan usage during the heating season).

Section 2. Calculation Methodology

The calculation methodology outlined in this section is a large scale analysis of the efficiency of Nest customer thermostat set point schedules with projected heating and cooling savings as compared to baseline behavior using pooled Fixed Regression Model and Comfort Temperature Analysis.

The table below outlines the differences between this workpaper and the initial interim gas savings workpaper submitted by Southern California Gas Company.

Work Paper Input	SCG Work Paper (previously submitted)	Nest-SCE Work Paper (this document)
Study design	Matched-comparison	Pooled fixed effects regression model and comfort temperature analysis
Sample size	~500 thermostats	Over 150,000 thermostats
Climate zones captured in input data set	8, 9, 10, 15, 16	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16
End-uses analyzed	Heating	Heating and cooling
NTG	Res default = 0.55	CA ET default = 0.85

1.0 Overview

The analysis of actual thermostat settings, combined with pooled fixed regression modeling, described in this paper provides estimates of energy savings from Nest Learning Thermostats installed in California's unique climate zones, which are widely understood to be generally milder than most regions in the United States. For a broader assessment of Nest's energy savings based on pre/post billing data analysis across the United States, please see the white paper "Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results," released by Nest in February, 2015.[4]

The results of the analysis herein demonstrates that, even though California's climate tends to be milder than the rest of the U.S., the energy savings driven by Nest Thermostats are still significant and impactful and could serve as a cost effective addition to residential energy efficiency program portfolios. The percentage savings results estimated in this analysis (see Section 3) are comparable to the percent savings from billing analysis studies from other regions. The Energy Savings white paper, which included results from across the U.S., found 10-12% of heating usage savings and electric savings equal to about

[4] Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results, Feb. 2015. https://nest.com/downloads/press/documents/energy-savings-white-paper.pdf

15% cooling usage.[5] The results of this analysis of California thermostats estimates average savings on the very same order-of-magnitude as the white paper: 11.5% of cooling use savings and 15% of heating use savings.This analysis used data only from California thermostats and leveraged a different methodology than the studies summarized in the White Paper above. As such, it is affirming to have found savings results that are so similar. It is worth noting that the percent savings are similar, as expected, but that the absolute savings values shown are lower for CA customers than customers in less mild climates (this result is to-be-expected).

1.1 Data for California work paper

The purpose of this paper is to provide an energy savings analysis in support of a deemed measure work paper for smart thermostats in California. The analysis herein is based on more than 13 million days of data from more than 100,000 Nest Learning Thermostats across California and includes savings estimates by climate zone for both cooling and heating HVAC consumption (as well as electric savings from reduced furnace fan usage during the heating season).

1.2 Methodology Overview -- Leveraging the emerging EnergySTAR®metric

The overall energy savings estimation is based on four steps:

1. **Analyze Nest customer temperature set points to assess the efficiency of their schedules.** This analysis calculates average (i.e., mean) set points and "comfort temperatures" for the heating and cooling seasons for each customer. The "comfort" temperatures -- defined as the 90th percentile of the customer's heating set points and the 10th percentile of their cooling set points -- are meant to represent typical settings when people are home and want to be comfortable. This definition matches the current working definition being used by the EPA in their development of a smart thermostat metric for EnergySTAR®.
2. **Estimate the percent change in heating and cooling runtime per degree change in temperature set point using a regression model fit separately for each climate zone.** This step is also similar to the current EPA metric except it employs a pooled model rather than aggregating across individual device-specific models.
3. **Estimate the heating and cooling energy savings compared to a constant set point at the comfort temperature.** The savings are calculated based on the savings per degree set point change found in step 2 and the difference between the average and comfort temperatures calculated in step 1. Again, this basic approach is being used in the EPA metric.
4. **Adjust the overall savings calculated in step 3 to account for customer's maintaining more efficient average baseline set points than a constant comfort temperature.** This step is not being used in the EPA metric because the EPA goal is to develop a metric of schedule efficiency.

[5] Energy Savings from the Nest Learning Thermostat: Energy Bill Analysis Results, Feb. 2015, p2.

Energy savings could then be calculated as the difference between a thermostat's efficiency metric and the efficiency of any specified baseline condition

This methodology is based on actual smart thermostat temperature settings compared to an occupant's preferred comfort temperature (i.e. the temperature most likely "set" on manual thermostats or older programmable thermostats that are used in 'hold' mode or without an effective schedule). Temperature setbacks on smart thermostats, like the Nest Learning Thermostat, are driven by features like Auto-Schedule and Auto-Away that work to automatically generate more efficient schedules for customers.[6] As previously mentioned, the structure is quite similar to the current metric under development by EPA.

It is also worth noting that the software that drives smart thermostats, like the Nest Learning Thermostat, will only continue to improve over time, which will help to continuously improve the energy savings delivered by such devices (an encouraging concept given the already promising results included herein). For example, Nest now allows customers to leverage the location of their mobile phones as an added data point to help inform the Auto-Away feature.

1.3 Model input data

This analysis was conducted with actual data from some Nest Thermostats currently in use throughout the state of California. Most notably, the model is built on the following data:

- The average set points and comfort temperature calculations were based on heating and cooling runtime weighted averages for more than 150,000 Nest thermostats in California with data covering the full year of May 2015 through April 2016.
- The pooled fixed effects regression modeling, which assessed the energy savings per degree set point change, was based on data from more than 100,000 thermostats and included more than 6M device-days of heating data (from January, 2016 - February, 2016) and more than 7M device-days of cooling data (from July, 2015 - September, 2015). The regression model sample was restricted to single stage HVAC systems to avoid the uncertainty introduced by the unknown relative capacities of the stages.

2.0 Methodology Details

2.1 Determining individual customer comfort temperature

[6] For more details on Auto-Schedule, please visit https://nest.com/support/article/How-does-Auto-Schedule-learn; for more details on Auto-Away, please visit https://nest.com/support/article/What-is-Auto-Away; and for details on the new enhancement to Auto-Away that allows customers to leverage the location fo their mobile phones, please see this description of our new Home/Away Assist feature https://nest.com/blog/2016/03/10/introducing-family-accounts-and-home-away-assist/

The methodology leverages the concept of a comfort temperature, which can be thought of as the temperature at which a given individual prefers to keep their home during a particular season.

- **Heating season comfort temperature:** a customer's preferred temperature during the Winter.
    - Defined as the 90th percentile of target temperature setpoints for a particular customer throughout a heating season (i.e. only 10% of the time during the heating season does this customer have a warmer temperature setpoint).
    - This comfort temperature is automatically calculated by each Nest Thermostat for each month. The seasonal average comfort temperature for each customer was calculated as the heating run-time weighted average across the season.

- **Cooling season comfort temperature:** a customer's preferred temperature during the Summer.
    - Defined as the 10th percentile of target temperature setpoints (i.e. only 10% of the time during the cooling season does this customer have a cooler setpoint).
    - Same calculation approach as for heating season.

Figure 1 shows heating comfort temperatures for a few customers compared with time series plots of hourly temperatures.

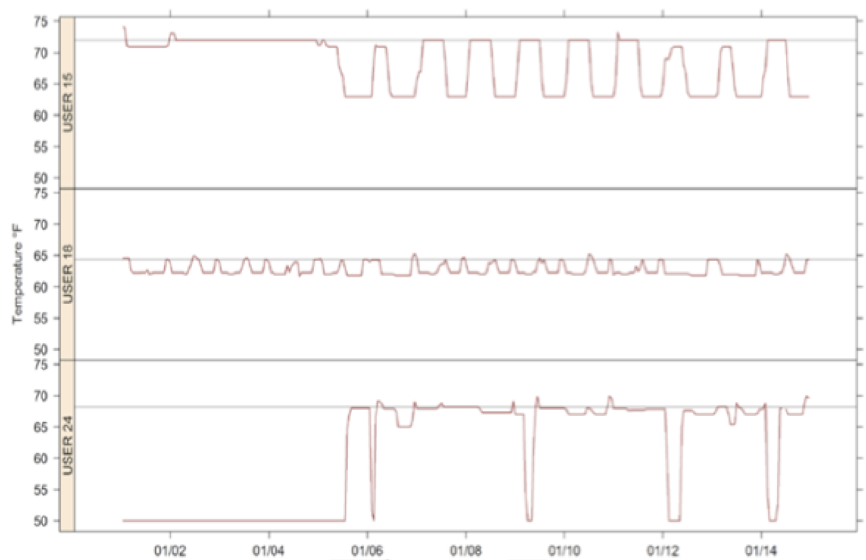

Figure 1: "Comfort" temperature = 90th percentile of heating setpoints. This chart shows that comfort temperature, in this case at the 90th percentile, can be reliably calculated and subsequently compared to average setpoints. As you can see, the 90th percentile is a good characterization of the common temperature people prefer when they are at home and want to be comfortable.

2.2 Average setpoints vs. comfort temperature

The comfort temperature described above defines a baseline condition of a flat schedule (i.e. one without heating set-backs or cooling set-ups). The difference between the actual average setpoints and the comfort temperatures for each device is a measure of the efficiency of each customer's schedule resulting from Nest's feature set and customer preferences. We recognize that the flat comfort temperature baseline may understate the efficiency of prior thermostat setting behaviors and so we added a final step to adjust the calculation results to reflect a more efficient baseline.

Figures 2 and 3 below show the average comfort temperatures and average setpoints aggregated by climate zone. The connecting lines in each chart illustrate the impact of setbacks on the set point.

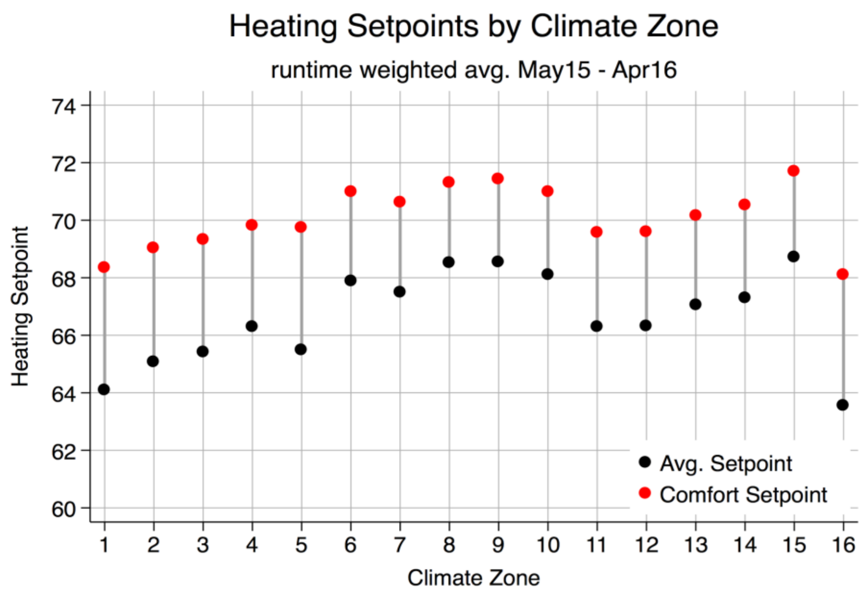

Figure 2: Heating setpoints by climate zone (runtime-weighted average May 2015 - April 2016). The data show a clear difference between comfort temperature and average setpoints. This difference drives a decrease in HVAC runtime and therefore energy savings.

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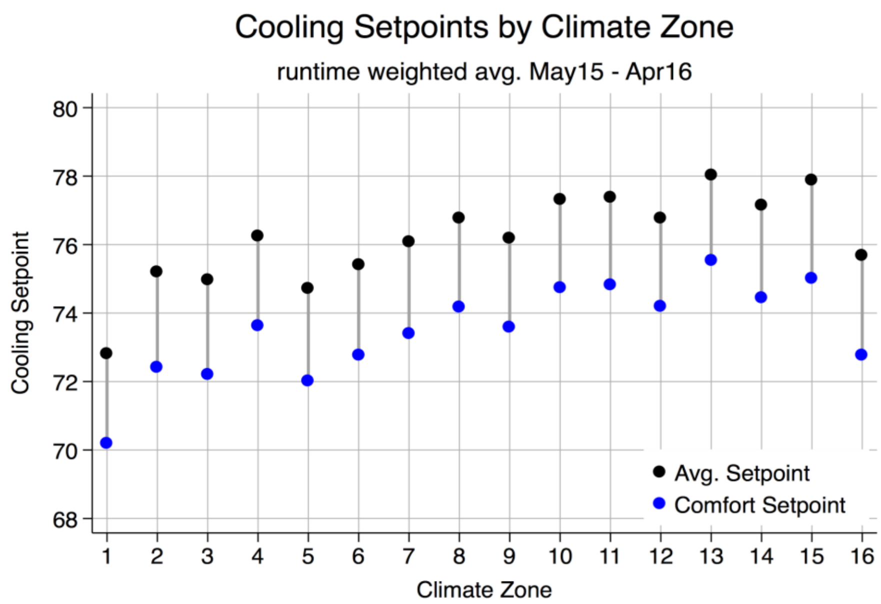


Figure 3: Cooling setpoints by climate zone (runtime-weighted average May 2015 - Apr 2016). The data show a clear difference between comfort temperature and average setpoints..

2.3 Pooled Fixed Effects Regression Model

The analysis of set points provides an estimate of the difference between the baseline comfort temperature and the average actual set points for each thermostat. The impact of these changes on HVAC run time, and on energy use, need to be estimated. The next step in the analysis was to fit a pooled fixed effects regression model to estimate the impact of thermostat set points on HVAC run time, accounting for weather. This analysis estimates the HVAC runtime savings expected from each °F reduced from an occupant's comfort temperature. This regression analysis modeled average daily HVAC runtime as a function of degree days (HDD60 for heating and CDD65 for cooling) and average set point and included thermostat level fixed effects. A separate model was fit for each climate zone. The output of the regression models -- expressed as percent HVAC runtime reduction per degree F -- are shown in Section 3.

2.4 Calculating energy savings

After fitting the regression models, the raw percent energy savings for each climate zone were calculated as the difference between comfort and actual set points multiplied by the percent savings per degree F for that climate zone. These percent savings were then used to estimate kWh and therm savings by multiplying them by the product of the average heating and cooling run times in each climate zone and the estimated system input capacities (as estimated by a climate-based Nest algorithm, discussed in Section 3). The raw savings from these calculations were then adjusted for a more efficient baseline.

2.5 RASS Base Case Calibration

Why it's needed

To ensure the baseline approach outlined in this workpaper follows an approach similar to the 2004-2005 DEER update[9] (which updated the savings estimate from a base case of a flat-schedule to a blended average schedule based on RASS data), the analysis outlined in Section (2.0) needs to be adjusted as well to account for the fact that by definition the EPA savings methodology leveraging the comfort temperature utilizes a flat-schedule base case. The RASS database confirms the fact that a portion of California customers do in fact have a setback schedule. Also, utilizing a flat-schedule baseline is inappropriate for a workpaper as it would asses the maximum savings versus the average savings appropriate for a deemed measure.

Approach

The 2009 Residential Appliance Saturation Study (RASS)[10] resulted in end-use saturations for 24,464 individually metered and 1,257 master-metered households and administered as a mail-in study. The sections of particular relevance to this workpaper are the Space Heating and Spacing Cooling Questions. One specific question in each section had a purpose of determining average thermostat temperature setpoints and are shown below as question B6 and C6. The average heating customer that had a flat schedule would select all of the bubbles in the 66-70° column. Those that utilize a setback schedule would move their answer up or down a column - signifying thermostat setting movement during that time period. There were roughly 10,200 heating customers and 5,800 for cooling across California who answered this question - making it one of the more robust datasets on self-reported thermostat behavior.

B6 If your main heating system is controlled by a thermostat, what is the average thermostat temperature usually set for each time period during the heating season?
(Choose one answer for each time period. Provide the average setting if it varies.)

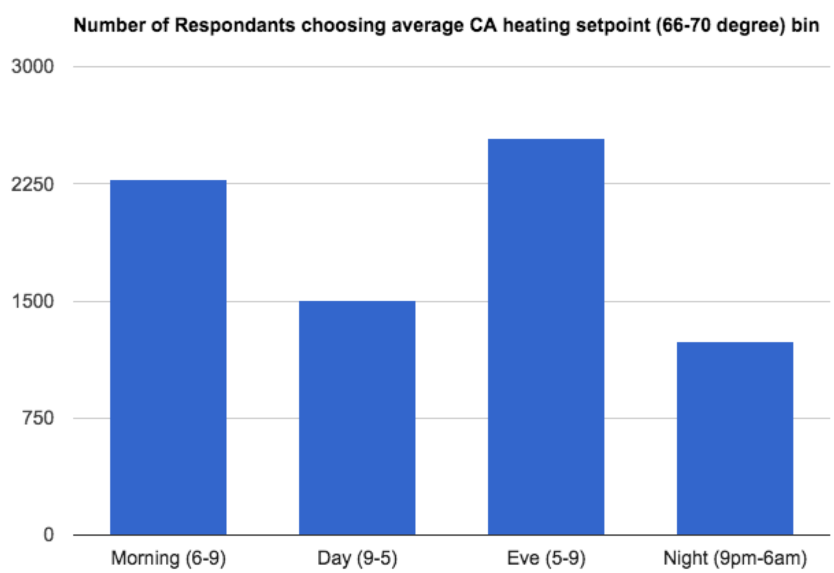
	Off	Below 55°F	55 – 60°F	61 – 65°F	66 – 70°F	71 – 75°F	Over 75°F
Morning *(6am-9am)* (HMRNSET)	1	1	1	1	1	1	1
Day *(9am-5pm)* (HDAYSET)	1	1	1	1	1	1	1
Evening *(5pm-9pm)* (HEVNSET)	1	1	1	1	1	1	1
Night *(9pm-6am)* (HNITESET)	1	1	1	1	1	1	1

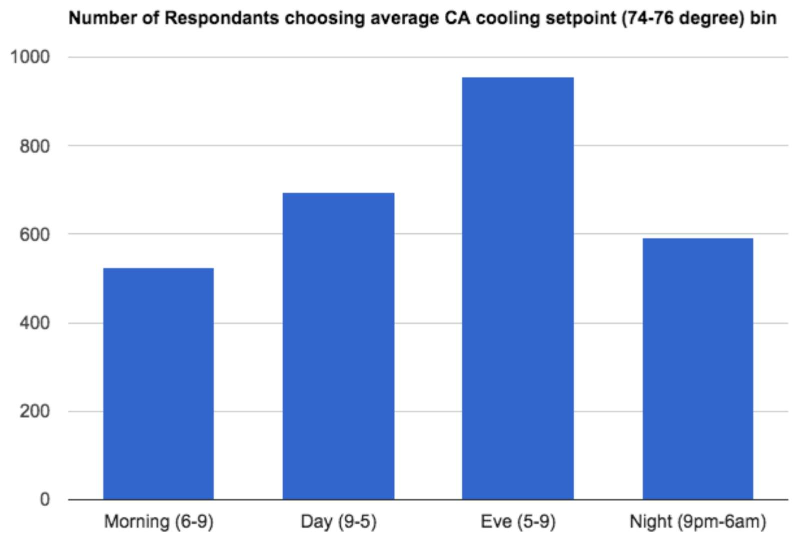
C5 What is the typical thermostat temperature setting of your main central cooling system for each time period during the cooling season? *(Choose one answer for each time period.)*

	Off	Below 70°F	70 – 73°F	74 – 76°F	77 – 80°F	Over 80°F
Morning *(6am–9am)* (CMRNSET)	1	1	1	1	1	1
Day *(9am-5pm)* (CDAYSET)	1	1	1	1	1	1
Evening *(5pm-9pm)* (CEVNSET)	1	1	1	1	1	1
Night *(9pm-6am)* (CNITESET)	1	1	1	1	1	1

A key question for our analysis is what percentage of customers utilized a thermostat schedule that included setbacks. To create a baseline percentage, we analyzed the compiled answers[11] for Single Family Home responses and analyzed how schedule patterns changed throughout the day. To begin, we examined the average heating and cooling setpoints as found in the RASS study and compiled in DEER 2004-2005 supporting analysis[12]. The average heating setpoint is 66.8 and the average cooling setpoint is 75.4. If all RASS respondents had a flat schedule set at the average temperature setpoint, they would have filled in the circle in the 66-70° F column and 74-76° f column for cooling.

As described, temperature setpoint movement out of the average column was used to estimate the percentage of customers who have day or nighttime setbacks in their thermostat schedule.





As can be seen in the charts, had everyone reported they had a flat schedule, these charts would be flat across. In the heating setpoint chart for example, you can see a clear reduction in the number of people in the average temp range during the day and night. To calculate the percent of customers with a setback schedule, we used the difference in the fraction of customer responses from evening to night as it is the most conservative approach (i.e. results in a higher % of customers with setback schedules for their baseline). The calculations used are outlined below and the baseline correction factors are listed in Table 2.1. The night setback percentage was calculated for both heating and cooling.

<u>Night Setback Customers</u>

% of customers with night setback schedules = (# evening respondents - # of night respondents) / (# evening respondents)

Table 2.1. RASS Baseline Correction Factors

	Correction Factor
Heating	51%
Cooling	38%

These calibration factors are then applied (multiplied) to the heating and cooling savings estimates generated through the comfort setpoint analysis (which generates a flat-schedule savings estimate) to develop the RASS baseline adjusted savings result tables as outlined in Section (3). This approach is very likely being overly conservative at this point as it essentially eliminates any potential savings customers that have a night setback might generate through features like auto-away as captured through occupancy sensors. We feel this calculation method ensures that the workpaper savings are based on the best available data as well as being a conservative estimate. If more data or analysis becomes available to quantify those savings in the future they should be reviewed for potential inclusion.

This approach reduces the estimated savings compared to the initial 33.3% baseline correction factor previously proposed and reviewed CalTF and Energy Division. That 33.3% factor had been developed to align this overall savings estimation approach with prior billing analysis based studies of Nest savings. . Adjusting the factor upwards based on self-reported behaviors leads to lower estimated savings -- making the overall savings estimates even more conservative and based on best available data (RASS).

3.0 Results

3.1 Heating and cooling savings by CA climate zone

Table 1 shows the key results from the analysis by climate zone. The T-diff columns shows the average difference between the comfort temperature and actual average set point for each climate zone. The % Savings/°F columns show the estimated percent change in HVAC run time per degree change in set point. The Savings columns show the overall results from calculating energy savings using the T-diff and % Savings/°F columns in a calculation with the average annual HVAC run time hours (for the period May 2015 through April 2016) and the estimated average HVAC system input capacities, and then reducing those savings the RASS Base Case calibration factor as outlined in Section 2.5.

Table 1: Savings by CA Climate Zone. This table shows that the analysis found meaningful kWh and therm savings across California's climate zones (no results shown for Climate zone 1 because of a limited sample size of data). Absolute savings values are higher inland, but still impactful in coastal zones.

California Climate Zone	Cooling T-diff (comfort temp - avg actual setpoint)	% Cooling HVAC Savings/degree Fahrenheit difference (regression output)	Cooling Savings (kWh)	Heating T-diff (comfort temp - average actual setpoint)	% Heating HVAC Savings/degree Fahrenheit difference (regression output)	Heating Savings (therms)	Heating Savings (kWh from furnace fan)
CA1	Cooling sample too small - leverage kWh savings from furnace fan reduction			4.27	10.9%	**49**	**26**
CA2	-2.79	-8.1%	**123**	3.96	9.5%	**31**	**26**
CA3	-2.77	-7.6%	**84**	3.91	9.5%	**29**	**18**
CA4	-2.63	-7.8%	**96**	3.54	8.7%	**21**	**17**
CA5	-2.71	-6.1%	**77**	4.27	7.9%	**20**	**14**
CA6	-2.64	-7.8%	**106**	3.08	9.1%	**10**	**8**
CA7	-2.68	-7.6%	**113**	3.14	9.6%	**10**	**8**
CA8	-2.60	-7.5%	**143**	2.79	8.0%	**8**	**7**
CA9	-2.60	-7.0%	**207**	2.89	7.5%	**12**	**14**
CA10	-2.56	-8.2%	**196**	2.88	8.2%	**10**	**11**
CA11	-2.56	-10.1%	**261**	3.29	9.7%	**23**	**28**
CA12	-2.57	-9.0%	**178**	3.26	9.4%	**23**	**25**
CA13	-2.50	-9.6%	**319**	3.11	9.8%	**19**	**23**
CA14	-2.70	-8.9%	**275**	3.22	9.0%	**25**	**27**
CA15	-2.86	-9.2%	**391**	2.99	10.8%	**7**	**11**

CA16	-2.93	-8.4%	**167**	4.56	7.8%	**56**	**35**

3.2 System sizing assumptions shown in Table 2

Table 2: System Sizing Assumptions. These values are averages across thermostats and were generated based on an automated system sizing algorithm developed by Nest and primarily driven by local design temperatures. These assumptions can be easily changed if any sources are available from California-specific research.

California Climate Zone	Air Conditioner kW	Furnace Btu/hr	Furnace Fan kW
CA1	Not used		
CA2	3.43	58895	0.49
CA3	2.28	53397	0.33
CA4	2.62	55165	0.44
CA5	2.30	57544	0.41
CA6	2.03	45723	0.37
CA7	2.33	48991	0.41
CA8	2.74	51543	0.48
CA9	3.75	54349	0.66
CA10	3.64	55694	0.64
CA11	4.09	60441	0.72
CA12	3.78	59338	0.66
CA13	4.15	60476	0.73
CA14	4.28	71035	0.75
CA15	4.27	54380	0.77
CA16	3.52	81337	0.50

SECTION 3. LOAD SHAPES

The closest load shapes that are applicable to the measures in this work paper are listed in the table below.

Building Types and Load Shapes

Building Type	Load Shape	E3 Alternate Building Type
RES	DEER:HVAC_EFF_AC	-

SECTION 4. COSTS

This wp consulted three readily available sources to document base case, measure case and incremental measure costs including:

1. 2010-2012 Work Order 17 Ex-Ante Measure Cost Study Final Report
2. 2008 DEER Measure Cost Summary Spreadsheet
3. Online Retailers Point of Sale Data

4.1 BASE CASE COST

2010-2012 Work Order 17 Ex-Ante Measure Cost Study Final Report

The 2010-2012 Work Order 17 (WO17) Ex-Ante Measure Cost Study Final Report was first consulted to see if updated base case costs were provided for setback programmable thermostats. WO17 does not provide base case costs for setback programmable thermostats. Given that WO17 does not provide base case costs for setback programmable thermostats, the 2008 DEER Measure Cost Summary Spreadsheet was consulted.

2008 DEER Measure Cost Summary Spreadsheet

The base case material cost for setback programmable thermostats within the DEER Measure Cost Summary (05_30_2008) Revised (06_02_2008) amounted to $94.12 as shown in **Table 14**.

Online Retailers Point of Sale Data

Research was done at common online retailers' websites for point of sale data to assess the reasonableness of the 2008 DEER Measure Cost Summary Spreadsheet since the 2008 DEER cost data is approximately 8 years old. The prices found across these online retailer websites ranged from $19.45 to $145.40 with the average material equipment cost for all twenty-nine applicable setback programmable thermostats to be $57.13.

Therefore, this wp uses the 2008 DEER Measure Cost Summary Spreadsheet setback programmable thermostat material equipment cost of $94.12 as the base case cost because the 2008 DEER Measure Cost Summary Spreadsheet takes into account sales volume in addition to retail pricing.

Table 15. DEER 2008 Base Case Costs for Setback Programmable Thermostats

Cost Case Description	Cost Case ID	Program Delivery Strategies	Material Cost
Setback Programmable Thermostats	ProgTStats	Downstream Prescriptive Rebates/Incentives	$94.12

4.2 Measure Case Cost

Smart Thermostats are not contained within WO17 or the 2008 DEER Measure Cost Summary Spreadsheet. Research was done at common online retailers for Smart Thermostats to support the measure equipment cost. The prices found across these online retailer websites ranged from $199 to $249 with the average material equipment cost for all six applicable Smart Thermostats to be $219.17. Until more updated studies are done, the online retail point of sales pricing is the best available data to support the measure equipment cost.

The 2008 DEER Measure Cost Summary Spreadsheet provides labor costs associated with installing programmable thermostats at $56.48. Since there are no additional wiring involved with installing Smart Thermostats compared to setback programmable thermostats, labor costs are assumed to the same in both the base case and the measure case at $56.48.

4.3 Full and Incremental Measure Cost

Responding to the July 19th, 2016 Interim SCG workpaper disposition, the measure application type reflects early retirement.

The incremental measure cost are shown in Equation 5 and Table 4.1.

Measure Case Equipment Cost ($219.17) – Base Case Equipment Cost ($94.12) = $125.05

Equation 5. Incremental Measure Cost Calculation

Table 4.1 Incremental Measure and Full Measure Costs

Installation Type	Incremental Measure Cost	Full Measure Cost	
		1st Baseline	2nd Baseline
ROB NEW/NC	(MEC + MLC) – (BEC + BLC)	(MEC + MLC) – (BEC + BLC)	N/A
RET/ER	(MEC + MLC) – (BEC + BLC)	MEC + MLC	(MEC + MLC) – (BEC + BLC)
REF;	(MEC + MLC) – (BEC + BLC)	MEC + MLC	N/A
REA	MEC + MLC	MEC + MLC	N/A

MEC = Measure Equipment Cost; MLC = Measure Labor Cost
BEC = Base Case Equipment Cost; BLC = Base Case Labor Cost

Full and Incremental Costs

Installation Type	Incremental Measure Cost	Full Measure Cost	
		1st Baseline	**2nd Baseline**
RET/ER	$125.05	$275.65	$125.05

ATTACHMENTS

Attachment 1) Full measure cost analysis and IMC analysis

Measure Cost Worksheet_Residential Smar

Attachment 2) Calculations of Baseline Adjustment Factor

RASS - Setpoint Change Analysis.xlsx

September 2, 2016

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