Smart Thermostats

A CLEAResult White Paper, prepared for Commonwealth Edison

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Introduction

A potential solution to the goal of increased electric savings at low costs is the addition of smart thermostats to the Illinois Residential portfolio, currently implemented by CLEAResult. Smart thermostats are designed to make automatic adjustments to temperature set points based on sensing periods of occupancy or vacancy in the home; using available local temperature data; and/or utilization of algorithms that "learn" the behavior of the home's residents. Information is gathered via occupancy sensors in the home or mobile phone detection, Wi-Fi connectivity, and consumer interaction with the thermostat. After a few weeks of use, learning algorithms in some models can detect patterns of set points and make adjustments based on occupancy preferences.

The fundamental question of this white paper is: ***Can smart thermostats be used to increase the kWh-saved-per-dollar-spent in ComEd's residential programming?*** The goal of this white paper is to summarize information gathered from pilot programs and studies surrounding potential savings from smart thermostat implementation, to determine the viability of this measure in a residential program in Illinois; and to present information on the various models of smart thermostats that could be available for implementation.

Background

Energy Star labeling of thermostats

The United States Environmental Protection Agency began to label programmable thermostats as "Energy Star" models in 1995, but this labeling was suspended at the close of 2009 due to uncertainty about consumer behavior and achievable energy savings from programmable thermostats[1].

While customers using the designed functionality of programmable thermostats are capable of achieving significant energy savings in their home, a California study suggested that fewer than 15% of programmable thermostat owners set separate programs for the weekend and weekdays, and a majority of users may not set a program at all.[2] In addition, a 1999 study by the Energy Center of Wisconsin found that behavior is an important component of energy savings with programmable thermostats. The learning and occupancy-sending capability of smart thermostats can achieve measurable energy savings without relying on specific attitudes or behavioral patterns, through bypassing the necessity of consumers being conscious and active about energy savings from their thermostats.

Smart Thermostats

Several pieces of functionality distinguish smart thermostats from other programmable models. First of all, smart thermostats can communicate with users remotely to allow reprogramming and monitoring over distance, typically through a Wi-Fi connection. Second, some smart thermostats are designed with algorithms that provide the capacity to "learn" standard programming behaviors of the user and thus eventually auto-program themselves, based on previous user inputs and/or occupancy, and without requiring regular attention from the user. Third, a smart thermostat is capable of detecting periods when the house is unoccupied, through either occupancy sensors or proximity detection of an occupant's mobile phone. Finally, smart thermostats can detect outdoor temperatures, using that information to improve automatic temperature adjustments.

The two thermostats examined for this whitepaper are the Nest thermostat, manufactured by Nest, and the Ecobee3, produced by Ecobee. The Honeywell Lyric and Allure Eversense are two other smart thermostats with similar features, but these two models currently lack any pilot studies or other reviews and will receive less focus in this whitepaper. Like other Wi-Fi enabled thermostats, all four models allow the user to connect remotely using a mobile app and check performance or adjust thermostat/HVAC settings when away from home. However, the learning and occupancy settings set these models apart as "smarter" thermostat models. The Nest thermostat uses an algorithm to recognize the settings you make to your home temperature (e.g. if you regularly lower the temperature to 60 while you sleep in the winter, the Nest will begin to make these adjustments automatically over time). Both the Nest and Ecobee3 thermostats also utilize motion sensors to detect occupancy and adjust thermostat settings accordingly. The Ecobee3 can link to multiple remote sensors to detect occupancy throughout the house, as well as learning the rate at which various parts of the house heat up, which allows

1 EnergyStar.gov. https://www.energystar.gov/index.cfm?c=archives.thermostats_spec. "Programmable Thermostats Specification."

2 Meier, A., et al. (Lawrence Berkeley National Laboratory and University of California Davis). "How People Actually Use Thermostats." Presented at American Council for an Energy Efficient Economy proceedings, Pacific Grove, California, August 15-20, 2010.

the system to optimize heating and cooling schedules based on occupancy patterns and idiosyncrasies of the space to be heated. The Lyric and Eversense utilize “geofencing,” detecting proximity of an occupant’s phone and thus determining whether to run the set program or go into an energy saving mode.

Not only do these four thermostats “learn” the user’s behavior, but they also feature settings that educate the user, providing opportunities for the user to adjust their behaviors to become more efficient. The Ecobee3 and Lyric send reminders to change filters and schedule HVAC maintenance; the Eversense provides the user with information on energy saving tips and products; and the Nest thermostat displays a green leaf whenever the thermostat is running at an energy-saving level, and it will inform the user what activity led to the greatest energy savings that day. The Lyric also emits a glow when the user has adjusted the temperature from the programmed setback, giving obvious visual cues to the occupant’s behavior.

Benchmarking Smart Thermostat Usage and Savings Pilots

Northern Indiana Public Service Company Nest Pilot Study

Northern Indiana Public Service Company (NIPSCO), in cooperation with Cadmus and CLEAResult, produced a report on an implementation of Nest brand smart thermostats alongside programmable thermostats in September of 2014, seeking to compare smart and programmable thermostats in relation to manual, non-programmable thermostats.[3]

Prior to this pilot study, users with programmable thermostats were found to leave their devices on constant set points more frequently than those with manual thermostats (those users typically had more variable set points, likely in response to outside temperature fluctuations), perhaps because of their difficulty in learning to use the programmable functionality. This supports the idea that standard programmable thermostats may be unlikely to achieve their potential savings due to user behavior.

400 programmable and 400 Nest smart thermostats were installed in randomly selected homes in northern Indiana (from June to September 2013), and 800 homes were used as a control group that continued previous use of manual thermostats. Through a combination of pre-/post-installation billing analyses (from June 2012 through September 2014), customer surveys, and metered data collection, Cadmus analyzed both customer behavior and energy savings for the control group and both test groups.

Cadmus and NIPSCO found that users with programmable thermostats in this study saved an average of 7.8% on their heating gas usage and 15.0% on electric cooling compared to the control population; while users with Nest thermostats saved an average of 13.4% on heating gas and 16.1% on electric cooling (see Table 1, below).

Table 1. NIPSCO Pilot Energy Savings as a percentage of total energy usage

	Gas Heating (therms)	Electric Cooling (kWh)
Programmable	7.8% (range 6% to 10%)	15.0% (range 10% to 22%)
Nest	13.4% (range 11% to 16%)	16.1% (range 10% to 22%)

Vectren Corporation Pilot Study

Vectren performed a similar pilot study to that run by NIPSCO, installing roughly 200 programmable thermostats and 200 Nest thermostats in their Southern Indiana service territory, and comparing energy usage to a control population of about 2,600 customers with manual thermostats installed in their homes. The thermostats for this study were installed between

3 The Cadmus Group, Inc. “Evaluation of the 2013-2014 Programmable and Smart Thermostat Program DRAFT.” November 13, 2014.

October 14, 2013 and January 24, 2014, and billing analyses were run from September 2012 through September 2014.

While the Vectren pilot study found sizeable energy savings, the achieved savings levels were 10% to 40% lower than those found in the NIPSCO study (see Table 2, below).

Table 2. Vectren Pilot Energy Savings as a percentage of total energy usage

	Gas Heating (therms)	Electric Cooling (kWh)
Programmable	5.0% (range 4% to 6%)	13.1% (range 7% to 19%)
Nest	12.5% (range 11% to 14%)	13.9% (range 9% to 19%)

Energy Trust of Oregon Nest Pilot Study

The Energy Trust of Oregon and CLEAResult implemented a Nest pilot study involving 185 Oregon homes heated via air source heat pumps, to determine whether these smart thermostats might represent a viable method of controlling customer electricity costs during the heating season, and if they should therefore be considered for inclusion in the Energy Trust's "Existing Homes" program. The implementers compared energy usage of these 185 Nest-installed homes to a control group of 211 homes selected from the same overall program population.

The results of this pilot study were that Nest users saved 781 kWh per year, or 12% of electric heating load.

Customer Satisfaction in Pilot Studies

In the NIPSCO pilot study in Indiana, 91% of users surveyed indicated they were "satisfied" or "very satisfied" with their Nest thermostat. The Energy Trust of Oregon customers rating the Nest thermostats as a 4 or 5 out of 5 were 79% in the initial customer satisfaction survey and 89% in the follow-up survey. These results indicate that not only are these thermostats effective at achieving significant energy savings, but they also achieve high customer satisfaction, an important component of program reach and long-term viability.

Ecobee Pilot Study

In 2012, Ecobee performed a brief study on savings estimates for customers utilizing the company's smart thermostats in Texas and Ontario.[4] Using data from Ecobee's Home IQ methodology, which analyzed the "relationship between equipment run time and indoor-outdoor temperature difference" (and compared energy use to an assumed base 72 degree setpoint),

4 Ecobee Inc. Ecobee 2012 Energy Savings Estimates, Version 2. August 12, 2013.

Ecobee found that customers saved an average of 23% on heating energy and 20% on cooling. Texas-specific savings were 21% and 20% for heating (gas furnaces and heat pumps, respectively), and 23% for cooling (central AC), while Ontario-specific savings were 17% for heating and 14% for cooling. The study suggests that customers manually set their thermostats to vary from the factory default settings, and that usage of the default could have increased savings to 31% for gas furnace heating, 32% for heat pump heating, and 44% cooling in Texas, and 21% for heating and 43% for cooling in Ontario.

Nest Pilot Study

In 2013-2014, Nest performed a brief study on energy savings achieved by about 700 of their customers around the nation, with over 15% of the study group in California and the rest split between 38 other states. The average number of heating degree days among study participants, 4,533, was compared to Baltimore, MD; and the average number of cooling degree days, 1,729, was compared to Charlotte, NC.

With a mixed baseline of programmable and manual thermostat users switching over to a smart thermostat, Nest found heating therm savings of 9.6% ±2.1% (735 participants) and kWh cooling savings of 17.5% ±2.9% (624 participants). Nest worked to ensure that these savings figures were not being influenced by other energy savings measures, whether the customer used a programmable or manual thermostat prior to Nest installation, or prior participation in Nest's MyEnergy savings program (though Nest data suggests that MyEnergy users are already more efficient than other customers, which could mean that the achieved savings from this study are lower than what might be seen in a program targeting a broader population).

Current State of Usage, Existing Programs

E Source, in its “Smart Thermostat Programs” report, detailed a variety of existing programs for smart thermostats, giving several examples of each type (programs relevant to this white paper are included)[5]:

BYOT (bring your own thermostat): Customer receives a rebate through the program for having a smart thermostat installed in their home

Pros: saves program money on installation and equipment costs; avoids contractor costs; customers can choose the thermostat they want

Cons: requires greater customer education, action; vendors must be involved

Program (state)	*Thermostats*	*Rebate*	*Program Overview*
Austin Power Partner Thermostat Pilot Program (TX)	Nest, Ecobee	$85	Earn rebate (up to 3/cust) for letting utility access Wi-Fi thermostat settings and schedule events
Avista Smart Thermostat Rebate (WA)	Nest, Ecobee, Lyric	$50 self-install, $100 contractor-installed	Standard prescriptive rebate; home must use 160 therms (if gas heat) or 4,000 kWh (if electric heat) to qualify

Enabling-Technology Bonus Incentives: Customer receives a rebate on their energy bill for using technology (such as a smart thermostat) to reduce energy usage during peak hours

Pros: no cost for installation or equipment; no infrastructure because onus is on customer

Cons: requires customer education; no predictable load reduction

Program (state)	*Thermostats*	*Rebate*	*Program Overview*
CPS Energy Nest Rush Hour Rewards Program (TX)	Nest	$85	Purchase Nest t-stat and enroll in program to receive an $85 bill credit; $30 add’l available for scheduled “rush” events during peak months

Special Rates: Customers receive special rates or incentives to install smart thermostats and decreasing AC usage during peak times

Pros: no cost for installation or equipment; good marketing tool for retail providers

Cons: requires customer education; customers don’t get a choice of thermostats

Direct Installation of a Free Thermostat: Utility provides a free smart thermostat to customers participating in the program, and contractors are sent out to install the thermostats

5 Krepchin, I. and L. Jacobson. 2014. Smart Thermostat Programs: Cutting energy use and demand. E Source.

Pros: increased reliability in load reduction estimation

Cons: high utility cost; customers don’t necessarily get a choice of thermostats

Program (state)	*Thermostats*	*Rebate*	*Program Overview*
Consolidated Edison, Inc. (NY)	Lyric	~$325	Customers receive free thermostat and installation (stated $300 value) and a $25 “thank you check”
CPS Energy Savers Smart Thermostat/Peak Savers Program (TX)	Lyric	~$300	Customers receive free thermostat and installation (stated $300 value)

Thermostat Buy-Down: Like the BYOT program, customers are given a rebate for a smart thermostat; unlike the BYOT program, customers install the thermostat themselves rather than having a contractor install

Pros: no cost for installation or equipment

Cons: customers may install incorrectly; customers don’t get a choice of thermostats

Program (state)	*Thermostats*	*Rebate*	*Program Overview*
Cambridge and North Dumfries Hydro’s Rush Hour Rewards Program (Ontario, Canada)	Nest	$200 (Canadian)	Customers with Nest thermostat can sign up for the program to receive $200 and be enrolled in up to 10 “rush hour events” in the summer
National Grid Nest Rebate Offer (MA)	Nest	$100	Instant rebate when purchasing a Nest thermostat

Key Figures and Basis

Description of Baseline Condition

The baseline condition for this measure is a manual (non-programmable) or programmable thermostat installed in the home. Where the customer does not indicate their existing thermostat type, the savings algorithm uses service territory averages to apply as an “unknown” baseline.

Description of Efficient Condition

The efficient condition is a smart thermostat installed in the home, replacing the existing thermostat. To qualify as a “smart” thermostat, the device must be Wi-Fi capable, with the Wi-Fi connection established by the customer; and the device must feature occupancy-sensing capability, such as motion sensors and/or geofencing.

Installation Rate

The NIPSCO pilot study in Indiana found that 82% of study participants connected their thermostats to the internet. It would be reasonable to expect a similarly high installation rate with any smart thermostat program in Illinois.

Net-to-Gross Ratio

Cadmus reported a 0.96 Net-to-Gross ratio for direct install Wi-Fi programmable thermostats in a 2012 Massachusetts pilot program.[6] Given the higher cost of smart thermostats, as well as low saturation in Illinois as reported by sales representatives for Honeywell, Ecobee, and Nest, a smart thermostat program is likely to see low free ridership and thus a strong NTG figure. For the purposes of this white paper, we assume the same 0.96 NTG found by Cadmus in the Massachusetts pilot program.

Expected Useful Life

Expected useful life for this measure is, as of yet, still somewhat uncertain. For programmable thermostats, a range of 10 to 15 years is standard. The Indiana Technical Reference Manual uses a 15-year EUL[7]; and multiple TRMs, including Illinois and Mid-Atlantic, use a 10-year EUL based on a GDS Associates report contracted by the New England State Program Working

6 Wi-Fi Programmable Controllable Thermostat Pilot Program Evaluation: Part of the Massachusetts 2011 Residential Retrofit and Low Income Program Area Evaluation. The Cadmus Group, Inc. September 2012.

7 Indiana Technical Reference Manual, version 1.0. TecMarket Works: Indiana Statewide Evaluation Team. January 10, 2013.

Group.[8] For the purposes of this whitepaper, it is assumed that a smart thermostat would have a 10-year measure life, similar to that of standard programmable thermostats.

Measure Cost

The average cost of the four smart thermostat models is around $250, based on retail prices for Nest, Ecobee3, Honeywell Lyric, and Allure Eversense thermostats.

Energy Savings Fraction for Smart Thermostats

Savings percentage estimates for customers installing smart thermostats ranged from 12% to 23% for heating savings, and 14% to 20% for cooling savings. As a relatively conservative midpoint, and because Indiana is directly adjacent to Illinois, savings from the NIPSCO and Vectren studies were averaged for our savings model. Resulting values are in Table 3.

Table 3. Thermostat Savings over Manual Baseline, based on Indiana Pilot Studies

	Programmable Heating Savings	Smart Heating Savings	Programmable Cooling Savings	Smart Cooling Savings
NIPSCO	7.8%	13.4%	15.0%	16.1%
Vectren	5.0%	12.5%	13.1%	13.9%
Indiana Average	6.4%	12.95%	14.05%	15.0%
Illinois Proposed Savings Factors	6.4%	12.95%	14.05%	15.0%

A smart thermostat would therefore save 12.95% on heating and 15.0% on cooling over a manual thermostat baseline, and 6.55% on heating and 0.95% on cooling over a programmable thermostat baseline.

Energy Savings for Smart Thermostats

The energy savings algorithm for cooling is taken from the Indiana TRM section on residential programmable thermostats, which estimates the cooling kWh usage of a home and multiplies that value by a cooling energy savings factor, indicating what percentage of a home's cooling kWh use is expected to decrease on average through the use of the thermostat being incentivized (this algorithm should only be used if the customer has central AC or an Air Source Heat Pump).

The energy savings algorithms for heating are taken from the Illinois TRM section on residential programmable thermostats. *****Where not referenced, assumed values and tables are taken from the Illinois TRM, v.4, section 5.3.11 on Programmable Thermostats.*

8 Measure Life Report Residential and Commercial/Industrial Lighting and HVAC Measures. GDS Associates, Inc. http://library.cee1.org/sites/default/files/library/8842/CEE_Eval_MeasureLifeStudyLights&HVACGDS_1Jun2007.pdf. June 1, 2007.

$\Delta kWh_{heating}$ = **%ElecHeat * Elec _Cons *** $ESF_{heating}$ *** HF + (ΔTherms *** F_e *** 29.3)**

ΔTherms = **%FossilHeat * Gas_Cons *** $ESF_{heating}$ *** HF**

$\Delta kWh_{cooling}$[9] = **(1/SEER) *** $EFLH_{cooling}$ *** MbtuH *** $ESF_{cooling}$

ΔkW[10] = $(\Delta kWh_{cooling}/EFLH_{cooling})$ *** CF * 20%**

Where

%ElecHeat = Percentage of heating savings assumed to be electric
Heating fuel

Heating fuel	%ElectricHeat
Electric	100%
Natural Gas	0%
Unknown	13%

Elec_ Cons = Estimate of annual household heating consumption for electrically heated single-family homes. If location and heating type is unknown, assume 11,613 kWh

Climate Zone (City based upon)	Electric Heat Pump Elec_Heating_ Consumption (kWh)
1 (Rockford)	12,789
2 (Chicago)	12,218
3 (Springfield)	10,464
4 (Belleville)	8,072
5 (Marion)	8,215
Average	**11,613**

HF = Household factor, to adjust heating consumption for non-single-family households

Household Type	HF
Single-Family	100%
Multi-Family	65%

$ESF_{heating}$ = Heating energy savings fraction (see table below[11])

$ESF_{cooling}$ = Cooling energy savings fraction (see table below[9])

Baseline	ESF_heating	ESF_cooling
Manual	12.95%	15.00%
Programmable	6.55%	0.95%
Unknown [12]	9.65%	7.57%

9 kWh cooling savings assumes Central AC in the home

10 kW algorithm from Illinois TRM section 5.6.1 Air Sealing. 20% is based on assumption that residents are not home 20% of the time during peak.

11 Evaluation of the 2013-2014 Programmable and Smart Thermostat Program DRAFT. Prepared for Northern Indiana Public Service Company. Cadmus Group. November 13, 2014.

F_e = Furnace Fan energy consumption as a percentage of annual fuel consumption (= 3.14%)

29.3 = kWh per therm

%FossilHeat = Percentage of heating savings assumed to be Natural Gas

Heating fuel	%FossilHeat
Electric	0%
Natural Gas	100%
Unknown	87%

Gas_Cons = Estimate of annual household heating consumption for gas heated single-family homes. If location is unknown, assume the average below

Climate Zone (City based upon)	Gas_Heating_ Consumption (therms)
1 (Rockford)	1,052
2 (Chicago)	1,005
3 (Springfield)	861
4 (Belleville)	664
5 (Marion)	676
Average	**955**

SEER = Actual SEER rating of existing unit or 10 if unknown

$FLH_{cooling}$ = Full load cooling hours; dependent on location and building type

Climate Zone (City based upon)	FLH_cool (single family)	FLH_cool (multi family)
1 (Rockford)	512	467
2 (Chicago)	570	506
3 (Springfield)	730	663
4 (Belleville)	1035	940
5 (Marion)	903	820
Weighted Average	**629**	**564**

MbtuH = Cooling system capacity; actual capacity, or if actual size unknown, 33.6 MBtu/hr for single-family buildings

CF = Coincidence Factor (=68%[13])

12 Percentages based on weighted average calculated by Cadmus using proportion of Indiana homes with programmable and manual thermostats

13 Illinois Technical Reference Manual Section 5.6.1 Air Sealing

Savings for a smart thermostat installed with each of the existing measures are detailed in Table 4, below (note: all variables with regional breakdowns assume the weighted average):

Table 4. Energy savings for smart thermostats in various scenarios

Measure	Type of Savings				
	Annual Therms	Lifecycle Therms	Annual kWh	Lifecycle kWh	kW Savings
Smart Thermostat, Gas Heat, Manual Baseline	123.67	1,236.7	407	4,070	0.063
Smart Thermostat, Gas Heat, Programmable Baseline	62.55	625.5	76	760	0.004
Smart Thermostat, Gas Heat, Unknown Baseline	92.20	922.0	233	2,330	0.032
Smart Thermostat, Electric Heat Pump Heat, Manual Baseline	0	0	1,797	17,970	0.063
Smart Thermostat, Electric Heat Pump Heat, Programmable Baseline	0	0	779	7,790	0.004
Smart Thermostat, Electric Heat Pump Heat, Unknown Baseline	0	0	1,269	12,690	0.032
Smart Thermostat, Unknown Heat Source, Manual Baseline	107.60	1,076.0	588	5,880	0.063
Smart Thermostat, Unknown Heat Source, Programmable Baseline	54.42	544.2	168	1,680	0.004
Smart Thermostat, Unknown Heat Source, Unknown Baseline	80.21	802.1	367	3,670	0.032
Smart Thermostat, Gas Heat, Manual Baseline (no cooling)	123.67	1,236.7	114	1,140	0
Smart Thermostat, Gas Heat, Programmable Baseline (no cooling)	62.55	625.5	58	580	0
Smart Thermostat, Gas Heat, Unknown Baseline (no cooling)	92.20	922.0	85	850	0
Smart Thermostat, Unknown Heat Source, Manual Baseline (no cooling)	107.60	1,076.0	294	2,940	0
Smart Thermostat, Unknown Heat Source, Programmable Baseline (no cooling)	54.42	544.2	149	1,490	0
Smart Thermostat, Unknown Heat Source, Unknown Baseline (no cooling)	80.21	802.1	220	2,200	0