ComEd and Nicor Gas Air Sealing and Insulation Research Report

FINAL

Presented to
Commonwealth Edison Company
Nicor Gas Company

September 24, 2018

Prepared by:

Carly Olig
Lindsay Bertrand
Michael Soda
Michael Freed

Navigant

www.navigant.com

NAVIGANT

ComEd and Nicor Gas Air Sealing and Insulation Research Report

Submitted to:

ComEd
Three Lincoln Centre
Oakbrook Terrace, IL 60181

Nicor Gas Company
1844 Ferry Road
Naperville, IL 60563

Submitted by:

Navigant.
30 S. Wacker Drive, Suite 3100
Chicago, IL 60606

Contact:

Randy Gunn, Managing Director
312.583.5714
Randy.Gunn@Navigant.com

Jeff Erickson, Director
608.497.2322
Jeff.Erickson@Navigant.com

Josh Arnold, Associate Director
608.497.2328
Josh.Arnold@Navigant.com

Kevin Grabner, Associate Director
608.497.2323
Kevin.Grabner@Navigant.com

Table of Contents

Table of Tables and Figures

E. EXECUTIVE SUMMARY

This report summarizes the findings of Navigant's air sealing and insulation research. The goal of the analysis is to provide an update to the Illinois Technical Reference Manual (TRM)[1] for energy savings associated with residential shell end-use measures currently incented through Illinois energy efficiency programs. Navigant assessed the electric and gas savings generated by each measure using two approaches: billing analysis and simulation modeling. The analyses estimated electric savings using ComEd data and gas savings using Nicor Gas data.

The TRM specifies two formulas for calculating savings for air sealing, using either actual before and after blower door readings or using annual kWh per measure and therm per measure savings based on the type of air sealing measures installed. The second approach contains a 0.8 adjustment factor to account for perceived over-claimed savings by the modeling study used to develop the savings numbers. The TRM states, "Though we do not have a specific evaluation to point to, modeled savings have often been found to overclaim. Further, VEIC reviewed these deemed estimates and considers them to likely be a high estimate. As such, an 80% adjustment is applied, and this could be further refined with future evaluations." Moreover, the TRM references a 2010 KEMA study which used billing data and modeling.[2]

The basement sidewall, floor, wall, and ceiling/attic insulation measure algorithms use actual R-values and insulation areas to calculate energy savings, but also contain an adjustment factor (0.8 for cooling and 0.6 for heating). The TRM states, "Adjustment factor to account for prescriptive engineering algorithms overclaiming savings, as demonstrated in two years of metering evaluation by Opinion Dynamics, see Memo 'Results for AIC PY6 HPwES Billing Analysis,' dated February 20, 2015."

Navigant's air sealing and insulation study was undertaken to use additional, Illinois-based research to update the TRM. We used both simulation modeling and billing analysis to estimate savings for the shell end-use measures. Combining these two methods allows us to review the robustness of the savings estimates. In cases where the two methods align, we can be more certain of the results and when they do not align, it can shed light on uncertainties. For measures such as air sealing and insulation, simulation modeling is a better approach than the engineering algorithms currently in the TRM because building energy models more accurately capture interactive effects for measures that increase or decrease the energy consumption of other end uses. Additionally, simulation modeling accounts for internal gains, solar gains, and the thermal mass of building assemblies, whereas engineering algorithms estimate the heat transfer through an assembly. As described below, based on this research Navigant recommends updating the adjustment factors rather than changing the TRM algorithms.

Table 1-1 summarizes the electric billing analysis, simulation modeling, and TRM algorithm results for the insulation and air sealing measures. Table 1-2 summarizes the natural gas results. Overall, across both fuel types, the billing analysis did not result in statistically significant savings estimates and had a high level of uncertainty[3]; although the point estimates of savings from the billing analysis and simulation modeling did not always align, the simulation modeling results were rarely outside the 90% confidence

[1] Illinois Statewide Technical Reference Manual for Energy Efficiency Version 6.0, available at: http://www.ilsag.info/technical-reference-manual.html.

[2] KEMA. 2010. "Evaluation of the Weatherization Residential Assistance Partnership and Helps Programs (WRAP/Helps)." Middletown, CT.

[3] This was likely due to (1) the low number of participants, especially for certain measures, (2) the high overlap in the measure installations because most participants installed some combination of the five shell measures rather than one measure alone, and (3) on the gas side, the low quality of the matches between the treatment and comparison groups.

interval of the billing analysis. However, on both the electric and gas side, the billing analysis and simulation modeling results were often on opposite sides of the TRM algorithm estimates.

For the billing analysis, in addition to estimating all the measures individually, we provide results for the air sealing and ceiling/attic insulation measures together. Combining these measures together considerably increased the precision for these measures as the two are installed together nearly all the time. On the electric side, the combined result was very similar to running the two measures individually. On the gas side, the combination was higher than the sum of the two individually, but the combined savings were closer to the simulation modeling and TRM savings than adding the two measures individually.

The team was not able to estimate savings for floor insulation in the simulation modeling because there were not enough participants who met the criteria needed for inclusion in the model. Navigant used the blower door test algorithm to calculate TRM air sealing savings because the ComEd and Nicor Gas air sealing programs use pre- and post-retrofit CFM50 values from blower door tests to calculate savings. To ensure apples-to-apples comparisons, the simulation modeling and the TRM estimates were based on the same weather data (2016) and participant measure characteristics as the billing analysis.

Table 1-1. Evaluated Electric Savings

Measure	Billing Analysis Savings (kWh/year) [90% Confidence Interval]	Simulation Modeling Savings (kWh/year)	TRM Algorithm Savings (kWh/year)
Air Sealing – Blower Door Algorithm	316 [-201, 833]	152	402
Ceiling/Attic Insulation	356 [-166, 878]	186	124
Air Sealing & Ceiling/Attic Insulation together	672 [485, 859]	338	526
Basement Insulation	-97 [-779, 585]	50	44
Floor Insulation Above Crawlspace	130 [-102, 362]	NA	11
Wall Insulation	49 [-198, 295]	41	83

Source: Navigant analysis

Table 1-2. Evaluated Natural Gas Savings

Measure	Billing Analysis Savings (therms/year) [90% Confidence Interval]	Simulation Modeling Savings (therms/year)	TRM Algorithm Savings (therms/year)
Air Sealing – Blower Door Algorithm	51 [-12, 113]	125	99
Ceiling/Attic Insulation	36 [-26, 98]	66	54
Air Sealing & Ceiling/Attic Insulation together	132 [112, 153]	191	153
Basement Insulation	22 [-29, 74]	10	21
Floor Insulation Above Crawlspace	-23 [-47, 1]	NA	7
Wall Insulation	17 [-12, 47]	28	57

Source: Navigant analysis

With the exception of air sealing and ceiling/attic insulation combined, the billing analysis did not result in statistically significant savings estimates and had a high level of uncertainty. For air sealing and ceiling/attic insulation combined, Navigant recommends using the billing analysis results to update the current cooling and heating adjustment factors in the TRM.[4] For all other measures, Navigant is has agreed not to recommend changes to the TRM at this time as stakeholders feel further research is needed to understand the differences between the TRM algorithms and the building simulation modeling used by Navigant.

Table 1-3 shows the current adjustment factors and the recommended adjustment factors for air sealing and ceiling/attic insulation based on the ratio of the billing analysis savings to the TRM savings. The TRM algorithm savings include the current heating and cooling adjustment factors in the TRM. The recommended gas heating adjustment factor is the ratio of the analysis savings after adjusting for efficient lighting to the TRM savings after applying the current heating adjustment factor.[5] However, the electric cooling and heating adjustment factors require an additional adjustment to the ratio because the analysis results are overall kWh savings from cooling and heating but the TRM adjustment factor only applies to cooling kWh savings. The cooling and heating adjustment factors are based only on the cooling and heating kWh savings, respectively.

A hyphen, "-", in the table indicates a case where we recommend no change to the current TRM adjustment factor. Navigant recommends one heating adjustment factor and one cooling adjustment factor for air sealing and ceiling/attic insulation combined because these measures are almost always installed together. For cases where air sealing is completed without attic insulation, Navigant is recommending a 100% adjustment factor, which ultimately results in no change in savings with the existing algorithm. Since this study did not look specifically at savings for electrically heated homes, Navigant is not recommended a change to the electric heating adjustment factor. Navigant recommends no change to the air sealing prescriptive infiltration reduction algorithm because the results of this research are based on pre- and post-retrofit CFM50 values from blower door tests. The blower door algorithm is the primary air sealing savings algorithm in the TRM, and the prescriptive infiltration reduction algorithm should be used only if a blower door test is not possible (e.g., large multifamily buildings).

Table 1-3. Current and Recommended Adjustment Factors based on Billing Analysis

Measure	Cooling Adjustment Factor		Heating Adjustment Factor - Therms		Heating Adjustment Factor - kWh	
	Current	Recommended	Current	Recommended	Current	Recommended
Air Sealing – Blower Door Algorithm	None Applied	100%	None Applied	100%	None Applied	100%
Air Sealing – Prescriptive Algorithm	NA*	NA	80%	-†	80%	-
Air Sealing & Ceiling/Attic Insulation together	None Applied & 80%	121%	None Applied & 60%	72%	None Applied	107%

* The TRM does not quantify cooling savings using the prescriptive algorithm.
† A hyphen, "-", in the table indicates a case where we recommend no change to the current TRM adjustment factor.
Source: Navigant analysis

[4] For the heating adjustment factor an adjustment was made to the billing analysis results before creating the recommended TRM adjustment factor to account for efficient lighting. For details see Sections 2.1.3 and 3.2.
[5] For example, for air sealing & ceiling/attic insulation together, the recommended heating adjustment factor is (132 therms + 3.1 therms) / (99 therms / 100% + 54 therms / 60%) = 72%.

1. INTRODUCTION

The goal of Navigant's air sealing and insulation research is to provide an update to the Illinois Technical Reference Manual (TRM) for energy savings associated with residential shell end-use measures currently incented through Illinois energy efficiency programs. There are five residential shell end-use measures in the TRM[6] which were studied in this research:

(1) Air Sealing

(2) Basement Sidewall Insulation

(3) Floor Insulation Above Crawlspace

(4) Wall Insulation

(5) Ceiling/Attic Insulation

The TRM specifies two approaches for air sealing, using either actual before and after blower door readings or using annual kWh per measure and therms per measure savings based on the type of air sealing measures installed. The second approach contains a 0.8 adjustment factor to account for perceived over-claimed savings by the modeling study used to develop the savings numbers. The TRM states, "Though we do not have a specific evaluation to point to, modeled savings have often been found to overclaim. Further, VEIC reviewed these deemed estimates and considers them to likely be a high estimate. As such, an 80% adjustment is applied, and this could be further refined with future evaluations." Moreover, the TRM references a 2010 KEMA study which used billing data and modeling.

The basement sidewall, floor, wall, and ceiling/attic insulation measure algorithms use actual R-values and insulation areas to calculate energy savings, but also contain an adjustment factor (0.8 for cooling and 0.6 for heating). The TRM states, "Adjustment factor to account for prescriptive engineering algorithms overclaiming savings, as demonstrated in two years of metering evaluation by Opinion Dynamics, see Memo 'Results for AIC PY6 HPwES Billing Analysis,' dated February 20, 2015."

Navigant's air sealing and insulation study was undertaken to use additional, Illinois-based research to update the TRM. We used both simulation modeling and billing analysis to estimate savings for the shell end-use measures. Combining these two methods represents Navigant's best practice for ensuring robust savings estimates. In cases where the two methods align, we can be more certain of the results and when they do not align, it can shed light on uncertainties. For measures such as air sealing and insulation, simulation modeling is a better approach than the engineering algorithms currently in the TRM because building energy models more accurately capture interactive effects for measures that increase or decrease the energy consumption of other end uses. Additionally, simulation modeling accounts for internal gains, solar gains, and the thermal mass of building assemblies, whereas engineering algorithms estimate the heat transfer through an assembly. As described through this report, based on this research Navigant recommends updating the adjustment factors rather than changing the TRM algorithms.

The remaining sections of this report present the methodology and findings of Navigant's research. Section 2 describes the billing analysis and simulation modeling methodology used to conduct this research. Section 3 describes the key results from this research and Section 4 summarizes Navigant's recommendations for TRM updates. The Appendices include details on the TRM algorithms and the simulation modeling calibration.

[6] These five measures are in section 5.6 "Shell End Use" of Volume 3 of Version 6 of the IL TRM. See: http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf

2. METHODOLOGY

Navigant evaluated the air sealing and insulation energy savings using both a billing analysis and simulation modeling. The following sections describe the billing analysis and simulation modeling methodology in greater detail.

2.1 Billing Analysis

Billing analysis estimates savings by comparing participant energy use after they begin experiencing the program treatment to a counterfactual baseline usage. This research relied on the quasi-experimental Matched Control Group (MCG) method to develop the counterfactual baseline (i.e., counterfactual use was based on energy use of a comparison group of customers who did not receive the treatment). The MCG method goes beyond simple random sampling of treatment and comparison groups by matching each treatment customer with a comparison group "best match" based on the pre-program energy usage. An evaluation protocol report authored at Lawrence Berkeley National Laboratory cites matching as a reasonable alternative to establishing baseline conditions when the "gold standard" of program evaluations, a randomized controlled trial, is not an option.[7] The MCG method is common in the economics literature – and the energy industry – for evaluations conducted with observational, rather than experimental, data.[8] After the MCG is chosen, regression analysis is used to estimate savings.

Matching on past energy use implies that matches and participants are, on average, observationally equivalent in the way that matters most (energy use), but they could be different in unobservable ways. Self-selection bias refers to the result that program savings are over- or under-estimated because participants behave differently than their matches due to unobservable factors that affect both the decision to participate *and* energy use. There is no way to control for self-selection bias in an opt-in program,[9] which is why experimental design is considered the "gold standard," and as such matching is a second-best evaluation technique which is used when an experimental design is unpalatable.[10]

2.1.1 Development of the Matched Control Group

Navigant selected control group matches by identifying the non-participant whose pattern of electric or gas usage most closely matched that of the participant in the 12 months before the participant joined the program. Each participant in the Nicor Gas program received a match based on their gas usage, and each participant in the ComEd program received a match based on their electric usage (e.g., a participant in the Nicor Gas Home Energy Savings (HES) program was matched with a non-participant Nicor Gas customer who had similar gas usage). If a customer participated in both the gas and electric program, separate matches were drawn for the purpose of measuring gas and electric savings. The main assumption of this method is that if two customers (a participant and their matched control) had very similar monthly energy consumption profiles in the 12 months before the participant installed the shell end-use measure, then their profiles would have continued to be similar if the participant had not installed

[7] State and Local Energy Efficiency Action Network. 2012. Evaluation, Measurement and Verification (EM&V) of Residential Behavior-Based Energy Efficiency Programs: Issues and Recommendations. Prepared by A. Todd, E. Stuart, S. Schiller, and C. Goldman, Lawrence Berkeley National Laboratory.
[8] See, for instance, Cameron, A. Colin, and P.K. Trivedi, *Microeconometrics: Methods and Applications,* Cambridge University Press, 2005.
[9] While there is an option to use future participants as a comparison group which is thought to limit selection bias, that method was not tenable here due to the sample size and time frame of participants available.
[10] For example, for air sealing and insulation it is logistically difficult to randomly assign customers to a treatment and control group and doing so could cause customer experience issues.

the measure. If this is the case, then the match provides a good approximation of what the participant's gas or electric use would have been in the absence of the program during the evaluated time period.

Navigant matched solely on energy usage data.[11,12] The MCG was selected by choosing the best non-participant match from a large pool of non-participants[13] for each participant based on minimizing the sum of squared difference in gas or electric usage over the 12-month period before a participant installed the shell end-use measure.[14] For each program participant, Navigant compared gas or electric consumption in each month in the period spanning one to 12 months before program enrollment to that of all customers in the available pool with billing data over the same 12 months. Participants with missing bills during the designated matching period, the 12 months prior to when they installed the measure, only selected a match if they had bills in at least eight of the 12 months.

The basis of the comparison for the match is the difference in monthly gas or electric use between a participant and a potential match, D_{PM} (**D**ifference between **P**articipant and potential **M**atch). The quality of a match is denoted by the Euclidean distance to the participant over the 12 values of monthly D_{PM} used for matching. The non-participant customer with the shortest Euclidean distance to a participant was chosen as the matched comparison for the participant. Matching was done with replacement, such that a non-participant could be the matched control for more than one participant.

Overall, the quality of the electric matches was good while the quality of the gas matches was low.[15] Figure 2-1 shows electric usage by participants and their matched controls during the matched period and Figure 2-2 shows gas. On the electric side, the average difference in usage in the matching period was -0.36%; on the gas side it was 6.18%. Since the difference in gas usage was relatively stable across the matching period, the lags on usage in Navigant's regression model (discussed in Section 2.1.2) should control for the pre-period differences between the participants and their matches. However, the low quality of the matches does add doubt to the regression results and makes the inclusion of the simulation modeling more important.

---

[11] Navigant tested running matches within zip code but found that this substantially reduced the quality of the matches. The difference between participants and their best match was roughly twice as high when matching within zip code compared to across zip codes. To account for differences across zip codes, a zip code indicator was included in the regression equation described in Section 2.1.2.

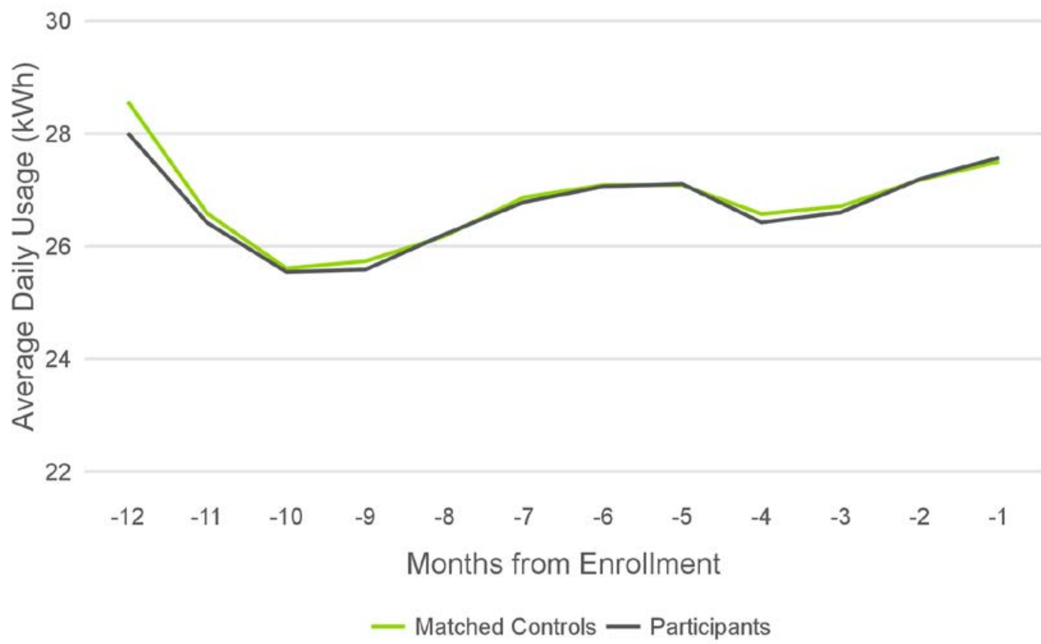
[12] Navigant also considered including home characteristic data from Nicor Gas's EnergyENGINE in the matching. The only data with enough completeness for consideration was building square footage. This value was missing for approximately 15% of non-participants and 5% of participants. The team did not find that including this value significantly changed the quality of the matches and thus decided to leave it out in favor of having a larger pool of customers to use in the regression since the sample size was an issue.

[13] The Nicor pool of non-participants consisted of 100,000 non-participants randomly selected by Nicor from their customer base to match the same distribution across zip codes as the PY3 to PY6 shell end-use measure participants. The ComEd pool of non-participants consisted of all the control customers for the Home Energy Report (HER) program who had data covering the period from June 2012 to April 2017, which was approximately 100,000 customers.

[14] If a customer installed more than one measure, as many of them did, Navigant matched on the 12 months before the earliest measure was installed and considered the period between installations to be a "blackout period" which is neither pre, nor post, installation.

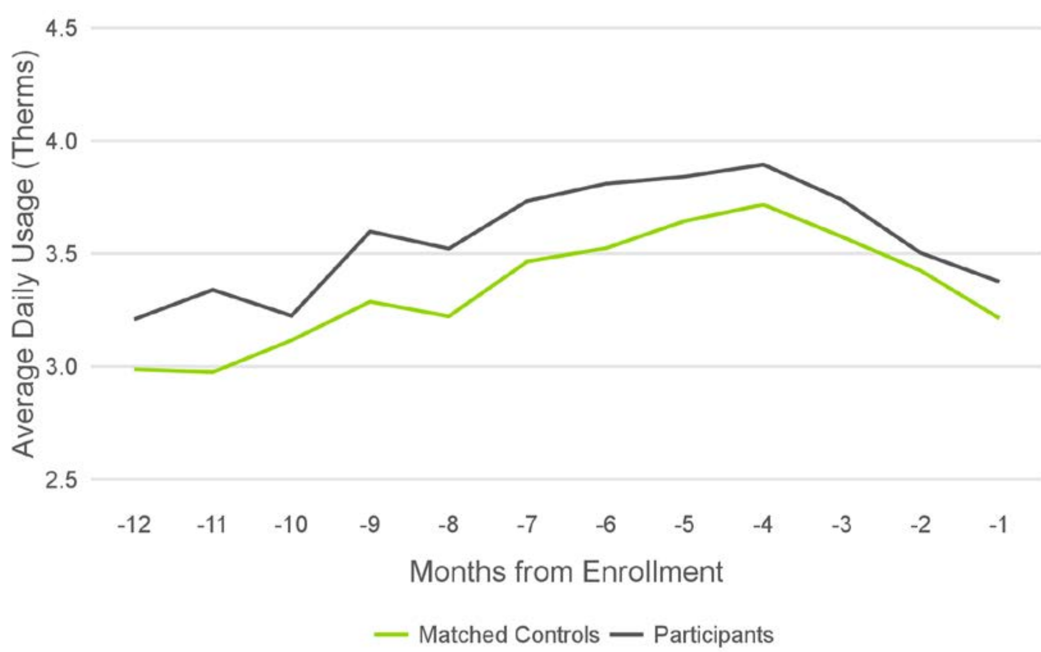
[15] Navigant did not request further data from Nicor to expand the pool of non-participant matches for two reasons: (1) the overlap of pre-period annual usage between the participant and non-participant pools was relatively high and we do not typically find that expanding the pool of non-participants beyond 100,000 customers results in significant gains in match quality when this is the case, and (2) to facilitate having results in time for the TRM V7 review process.

Figure 2-1. ComEd Participant and Matched Control Usage in Matching Period



Source: Navigant analysis

Figure 2-2. Nicor Gas Participant and Matched Control Usage in Matching Period



Source: Navigant analysis

2.1.2 Regression Analysis

After selecting matched controls, Navigant used regression analysis to estimate daily per-participant savings for each shell end-use measure. This regression was run separately to estimate gas and electric savings. Navigant's regression approach, Regression with Pre-Program Matching (RPPM), follows Ho et al.,[16] who argue that matching a comparison group to the treatment group is a useful "pre-processing" step in a regression analysis to assure that the distributions of the covariates (i.e., the explanatory variables on which the output variable depends) are the same for the treatment group as they are for the comparison group. This minimizes the possibility of model specification bias.

The regression model used only post-treatment period data in the dependent variable while incorporating pre-treatment period data as an independent variable. Equation 2-1 shows the model specification for the RPPM approach.

Equation 2-1. RPPM Model

$$\begin{aligned} ADU_{kt} = {} & \alpha_1 Treatment\_AirSealing_k + \alpha_2 Treatment\_CeilingAtticInsulation_k \\ & + \alpha_3 Treatment\_BasementInsulation_k + \alpha_4 Treatment\_FloorInsulation_k \\ & + \alpha_5 Treatment\_WallInsulation_k + \alpha_6 Other\_Measure_k \\ & + \sum_J \alpha_{7j} YrMo_{jt} + \sum_J \alpha_{8j} PREuse_{kt} \cdot YrMo_{jt} + \sum_L \alpha_{9l} Zip_{kl} + \varepsilon_{kt} \end{aligned}$$

where:

ADU_{kt}	is average daily energy usage by household k in month t
$Treatment\_xxx_k$	is a 0/1 indicator variable, taking a value of 1 if household k is a participant in the specified measure and 0 otherwise
$Other\_Measure_k$	is a 0/1 indicator variable, taking a value of 1 if household *k* installed another measure in the Nicor Gas HES program or the ComEd HVAC and Weatherization program[17]
$YrMo_{jt}$	is a set of binary variables taking a value of 1 when $j = t$ and 0 otherwise[18]
$PREuse_{kt}$	is average daily energy usage by household k during the most recent month before household k (or its match) installed the measure that is the same month as calendar month t
Zip_{kl}	is a set of binary variables taking a value of 1 when household k is in zip code l and 0 otherwise
ε_{kt}	is a cluster-robust model error term

In this specification, α_1 to α_5 are the savings estimates, where α_1 is for air sealing, α_2 for ceiling/attic insulation, etc. This specification allows the savings to be estimated for each measure, controlling for the installation of the other measures. This is important because most participants installed some

[16] Ho, Daniel E., Kosuke Imai, Gary King, and Elizabeth Stuart. 2007, "Matching as Nonparametric Preprocessing for Reducing Model Dependence in Parametric Causal Inference," *Political Analysis* 15(3): 199-236.
[17] The shell end-usage measures were also housed in ComEd's Home Energy Rebates and HES programs over the various years included in this study.
[18] In other words, if there are T post-program months, there are T monthly dummy variables in the model, with the dummy variable $Month_{tt}$ the only one to take a value of 1 at time t. These are, in short, monthly fixed effects.

combination of the five measures rather than one measure alone. The estimates are more precise for measures with more installations.

Navigant also tested running the model on combinations of measures that were commonly installed together (such as air sealing and attic insulation). The team found that the combined estimate of the savings was similar to the sum of the individual savings and therefore used the specification estimating the measures individually for easier comparison to the simulation modeling and TRM results. Due to the considerably increased precision when estimating air sealing and attic/ceiling insulation together, those results are also shown and compared to the simulation modelling and TRM.

Equation 2-1 estimates the savings that occurred during the time period analyzed. Importantly, this means it estimates the savings conditional on the specific weather conditions during the evaluation period, rather than producing a weather-normalized savings estimate. Navigant estimated savings for the calendar year 2016.[19] This was not necessarily the first year the measure was installed, since the participants go back to 2013, but the team does not expect the savings to vary much in the first few years after installation for reasons other than weather.

2.1.3 Adjustment for Efficient Lighting

The regression in Equation 2-1 did not directly account for the heating penalty[20] due to efficient lighting on the gas savings side. After running the regression, Navigant determined that 34% of the customers included in the gas billing analysis also installed efficient lighting.[21] Navigant used the following method to increase the gas savings such that they are not penalized by the heating loss from efficient lighting:

1. Calculated efficient lighting heating penalty per customer based on program tracking data using Equation 2-2.[22]

Equation 2-2. Heating Penalty Equation

$$\Delta Therms = \frac{-\left(\left(\frac{WattsBase - WattsEE}{1000}\right) * ISR * Hours * HF * 0.03412\right)}{\eta Heat}$$

Where:

$\Delta Therms$	Heating penalty if natural gas heated home
$WattsBase$	Wattage of baseline bulb
$WattsEE$	Wattage of efficient bulb
1000	Converts watts to kilowatts
ISR	In Service Rate, the percentage of units rebated that are actually in service
$Hours$	Average hours of use per year
HF	Heating Factor, or percentage of light savings that must be heated
0.03412	Converts kWh to therms

[19] Navigant did not have a full year of data for 2017.
[20] The heating penalty refers to the fact that customers may need to increase their level of heating due to loss of warmth from inefficient lighting (like incandescent bulbs) when efficient lighting (like CFLs and LEDs) is installed. Based on IL protocols, the utilities are not penalized for this increase in heating due to efficient lighting installations.
[21] Navigant considered overlaps with efficient lighting installed in ComEd's Home Energy Assessment and Multi-Family programs. Efficient lighting installed in the HVAC and Weatherization program is directly accounted for in the Other_Measure variable in Equation 2-1.
[22] This equation is from Section 5.5 of the Illinois TRM, Version 6.0.

$\eta Heat$ Efficiency of heating system

2. Calculated average value from Equation 2-2 for all customers with overlap between the air sealing and ceiling/attic insulation measures[23] and efficient lighting.
3. Multiplied the average value by 34% to account for the fact that not all customers have efficient lighting.
4. Increased the average therm savings from the billing analysis by the amount calculated in Step 3.

This increased therm savings value was the one used to create the recommended adjustment factor for the IL TRM.

2.2 Simulation Modeling

In parallel with the billing analysis, Navigant used a calibrated energy simulation approach to calculate gas and electric savings for shell end-use measures. The simulation modeling methodology included five main tasks:

1. Analyzing participant gas and electric billing data
2. Creating building energy models representing average program homes
3. Disaggregating billing data into end uses for building energy model calibration targets
4. Calibrating the building energy models to end use consumption estimates
5. Deriving measure-level savings by running building energy models with baseline and efficient characteristics from program tracking data

Navigant analyzed participant billing data provided by ComEd and Nicor Gas to determine electric and gas consumption targets for the building energy model calibration process. The team converted the data into energy consumption values for each calendar month and determined pre- and post-retrofit periods for each home using the installation dates in the program tracking data. Navigant received billing data for January 2012 to September 2017 and selected 2014 for the calibration period as this was the year with the largest number of participants in the pre-retrofit period.

Navigant uses hourly simulation software for evaluations that require building modeling to capture time-dependent energy impacts and interactive effects. The team used the Building Energy Optimization interface tool (BEopt) created by the National Renewable Energy Laboratory (NREL) to build the energy models in EnergyPlus, a modeling software also developed by NREL. Navigant created four building energy models which represent average program homes and used program tracking data to determine inputs for these models.

The model categories are (1) one story with finished basement, (2) two stories with finished basement, (3) one story with unfinished basement, and (4) two stories with unfinished basement. All models have gas space heating. Each model category included the homes that had complete billing data for the 2014 pre-retrofit calibration period. The one-story models included 231 homes and the two-story models included 326 homes. Navigant used the same models for finished and unfinished basements because the program audit data did not contain information on the breakdown between finished and unfinished basements.

[23] Only these two measures were considered as they are the only ones where recommendations went into the IL TRM.

For each model category, the team incorporated average home characteristics such as floor area, pre-retrofit R-values and infiltration rates, and equipment specifications from all homes in that category to build the model. When the program tracking data did not contain characteristics needed for the model inputs, Navigant used secondary sources such as ComEd and Nicor Gas baseline studies and Building America Benchmark data. The team did not model floor insulation above the crawlspace as there was not enough complete billing data and program audit data to support the analysis of this measure.

In preparation for building energy model calibration, Navigant disaggregated the pre-retrofit monthly electric and gas consumption totals into end uses for calibration targets using the Navigant billing data end use disaggregation tool. This tool is Navigant's standard practice and has been used for numerous residential evaluations. Appendix B includes a detailed explanation of the calibration tool. After completing the billing data disaggregation, Navigant calibrated the building energy models to match the pre-retrofit end use energy consumption targets. For the calibration modeling, the team used a 2014 weather file for the Chicago O'Hare airport to match the Illinois TRM climate zone of the participants and the billing data period used for calibration.

To determine measure-level savings, Navigant ran parametric models by modifying relevant measure parameters in the calibrated models while keeping all other model parameters constant. To compare the results to the billing analysis, the team incorporated average home and measure characteristics for the billing analysis sample into the models. For the savings analysis, the team used an actual weather file for calendar year 2016 to compare the results to the billing analysis. Navigant calculated per unit savings and used average insulation areas and infiltration reduction values for the billing analysis participants to calculate total measure-level savings.

2.3 Data Sources

Table 2-1 shows a summary of the data used for the billing analysis and simulation modeling.

Table 2-1. Data Sources

Data Type	Variables	Time Period
Tracking data for the program(s) that covers the shell end-use measures	• Utility Account ID • Installation Date • Measure Name	Program years ending in 2014, 2015, 2016, and 2017
Audit data for the program(s) that includes measure and home characteristics	• Home Type • Floor Area • Pre- and Post-Retrofit Insulation R-Values • Pre- and Post-Retrofit Infiltration • Heating System/Fuel Type • Heating System Efficiency • Cooling System Type • Cooling System Efficiency	Program years ending in 2014, 2015, 2016, and 2017
Monthly billing data for participants	• Utility Account ID • Energy (kWh or therm use) • Bill Start Date • Bill End Date • Bill Period Days • Zip Code	January 2012 – September 2017
Monthly billing data for a large pool of non-participant matches	• Utility Account ID • Energy (kWh or therm use) • Bill Start Date • Bill End Date • Bill Period Days • Zip Code	January 2012 – September 2017
Baseline study home characteristics	• Appliance Saturation and Fuel Type • Water Heating System/Fuel Type • Water Heating System Efficiency	Nicor Gas Market Potential Study Report: 2010 ComEd Residential Saturation/End Use Report: 2013

Source: Navigant

Table 2-2 shows the number of participants in each analysis after data cleaning. The precision of a billing analysis relies critically on the sample size; thus, all else equal, measures with fewer installations have lower precision (i.e., the confidence bounds are larger) than measures with more installations.

Table 2-2. Participant Counts

Measure	Billing Analysis		Simulation Modeling – Calibration	
	Electric	Gas	Electric	Gas
Air Sealing	2,734	1,942	482	530
Ceiling/Attic Insulation	2,722	1,938	502	552
Basement Insulation	30	35	9	9
Floor Insulation Above Crawlspace*	295	286	0	0
Wall Insulation	337	160	48	54
Total Unique Participants	2,783	1,954	507	557

* The floor insulation measure installations all occurred in the program year ending in 2014. Neither ComEd nor Nicor Gas completed any installations of that measures after that time.
Source: Navigant analysis

For the billing analysis, data cleaning included:

1. Removing installers of shell end-use measures who did not have an installation date
2. Removing observations with missing usage
3. Removing observations identified as outliers: observations more than one order of magnitude above or below the median usage
4. Removing installers of shell end-use measures who did not have at least eight out of 12 months of usage data during the matching period and usage data in 2016

Table 2-3 shows how many customers were removed in each step of billing data cleaning listed above.

Table 2-3. Billing Data Cleaning Removals

Data Cleaning Step	Participants Removed	
	Electric	Gas
Initial Unique Participant Count	4,232	3,071
Step 1	0	170
Step 2	0	2†
Step 3	0*	0‡
Step 4	1,449	945
Final Unique Participant Count in Analysis	2,783	1,954

* This step removed five electric observations for participants.
† This step removed 463 gas observations for participants.
‡ This step removed 66 gas observations for participants.
Source: Navigant analysis

For the simulation modeling calibration, data cleaning included:

1. Removing installers of shell end-use measures who did not have an installation date
2. Removing installers of shell end-use measures who did not have the number of stories in program tracking data

3. Removing installers of shell end-use measures who were not in the 2014 pre-retrofit period used for model calibration
4. Removing installers of shell end-use measures who did not have a full year of billing data in the 2014 pre-retrofit period used for model calibration

Table 2-4 shows how many customers were removed in each step of simulation model data cleaning listed above. Step 2 resulted in the loss of a significant number of participants because the number of stories was not populated for these participants in the program tracking data. The number of stories is an important home characteristic for building simulation modeling. To support research and evaluation activities in the future, Navigant recommends recording the number of stories for all participants installing air sealing and insulation measures.

Table 2-4. Simulation Modeling Cleaning Removals

	Participants Removed	
Data Cleaning Step	Electric	Gas
Initial Unique Participant Count	4,232	3,071
Step 1	0	170
Step 2	2,776	1,546
Step 3	745	563
Step 4	204	235
Final Unique Participant Count in Analysis	507	557

Source: Navigant analysis

2.4 Power Analysis

Navigant used a power analysis to predict the number of participants that would be necessary to get statistically significant results from a billing analysis for each measure. A power analysis starts with a known standard error for a given sample size. Navigant used the sample size, predicted savings, and standard error from this research. For each measure, we assumed the measure would continue to make up a similar proportion of all installations.

Navigant used the formula shown in Equation 2-3 to calculate the expected standard error for larger sample sizes. The subscript 0 indicates the parameters for the original assumptions (i.e., the results of this research) and the subscript 1 indicates the parameters for the new, larger sample.

Equation 2-3. Standard Error Calculation

$$SE_1(\hat{\beta}) = \frac{SE_0(\hat{\beta}) \cdot \sqrt{n_0} \cdot \sqrt{p_0 \cdot (1 - p_0)}}{\sqrt{n_1} \cdot \sqrt{p_1 \cdot (1 - p_1)}}$$

Where,

SE = standard error
β = the estimate of savings
n = the total sample size, treatment plus control customers
p = the proportion of the total sample size which is made up of treatment customers

It is important to remember that the power analysis is an estimation of expected results and the actual findings could differ from this expectation for several reasons including:

1. If the savings are different from the percentages assumed; lower savings would be less significant
2. If the energy savings are more variable than the results of this research; more variable savings would lead to less significance
3. If the energy usage is more variable than for the participants in this research; more variable usage would lead to less significance

3. Results

This section presents electric and natural gas savings estimates for the air sealing and insulation measures. Overall, the billing analysis did not result in statistically significant savings estimates and had a high level of uncertainty. This was likely due to (1) the low number of participants, especially for certain measures, (2) the high overlap in the measure installations because most participants installed some combination of the five shell measures rather than one measure alone, and (3) on the gas side, the low quality of the matches between the treatment and comparison groups. Additionally, there is high variability in the quality of installation for these measures which causes high variability in savings; this high savings variability also contributes to high uncertainty in the billing analysis results. Although the billing analysis and simulation modeling results did not always line up in terms of the point estimates of the results, the modeling results were rarely outside the confidence bounds of the billing analysis.

3.1 Electric Savings

Table 3-1 summarizes the electric billing analysis results for the shell end-use measures based on calendar year 2016 weather data.[24] As shown by the confidence interval and relative precision, none of the individual measure estimates are statistically significant at 90% confidence. To further illustrate the uncertainty, Figure 3-1 shows the 90% confidence interval for each measure. Even for the most precise measure, the confidence interval spans over 400 kWh per year. We also show air sealing and ceiling/attic insulation together for which the relative precision is much lower leading to a much tighter confidence interval.

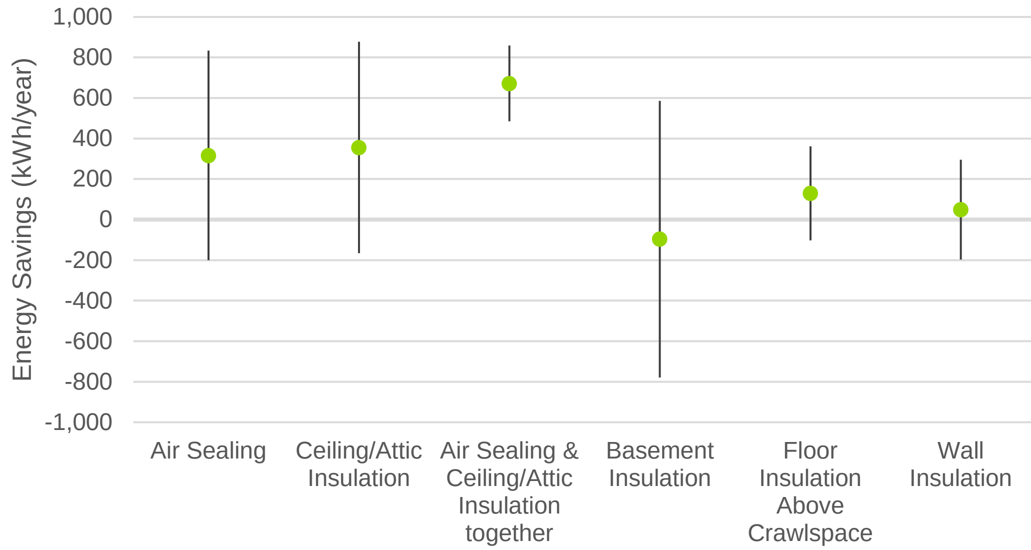
Table 3-1. Billing Analysis Electric Savings

Measure	Number of Participants	Energy Savings (kWh/year) [90% Confidence Interval]	Relative Precision at 90% Confidence
Air Sealing	2,734	316 [-201, 833]	164%
Ceiling/Attic Insulation	2,722	356 [-166, 878]	147%
Air Sealing & Ceiling/Attic Insulation together	2,722	672 [485, 859]	28%
Basement Insulation	30	-97 [-779, 585]	704%
Floor Insulation Above Crawlspace	295	130 [-102, 362]	179%
Wall Insulation	337	49 [-198, 295]	505%

Source: Navigant analysis

[24] For additional context, in percentage terms the absolute annual savings ranged from 0.6% to 3.6%. It is not uncommon to need very large sample sizes to achieve 90% statistical significance for savings of this magnitude. See Section 3.3 for more context on the customer counts we predict would achieve 90% statistical significance.

Figure 3-1. Billing Analysis Electric Savings with 90% Confidence Intervals



Source: Navigant analysis

Table 3-2 shows the average measure characteristics for the electric billing analysis participants.

Table 3-2. Electric Billing Analysis Participant Measure Characteristics

Measure	Number of Participants	Average Insulation Area (square feet)	Pre-Retrofit R-Value	Post-Retrofit R-Value	Average Infiltration Reduction (CFM)	Pre-Retrofit CFM	Post-Retrofit CFM
Air Sealing	2,734	NA	NA	NA	1,449	4,111	2,662
Ceiling/Attic Insulation	2,722	959	12.1	45.5	NA	NA	NA
Basement Insulation	30	336	5.0	15.5	NA	NA	NA
Floor Insulation Above Crawlspace	295	129	4.9	10.5	NA	NA	NA
Wall Insulation	337	318	4.9	17.8	NA	NA	NA

Source: Navigant analysis

Table 3-3 summarizes the electric billing analysis results, simulation modeling results, and TRM algorithm results for the insulation and air sealing measures. Navigant estimated both the simulation modeling results and the TRM algorithm results using 2016 weather data and the measure characteristics shown in Table 3-2 to ensure an apples-to-apples comparison with the billing analysis results. The team was not able to estimate savings for floor insulation in the simulation modeling because there were not enough participants who met the criteria needed for inclusion in the model. Appendix A shows the TRM algorithms and key inputs. Navigant used the blower door test algorithm to calculate TRM air sealing savings because the ComEd and Nicor Gas air sealing programs use pre- and post-retrofit CFM50 values from blower door tests to calculate savings.

Table 3-3. Evaluated Electric Savings*

Measure	Billing Analysis Savings (kWh/year)	Simulation Modeling Savings (kWh/year)	TRM Algorithm Savings (kWh/year)
Air Sealing – Blower Door Algorithm	316	152	402
Ceiling/Attic Insulation	356	186	124
Air Sealing & Ceiling/Attic Insulation together	672	338	526
Basement Insulation	-97	50	44
Floor Insulation Above Crawlspace	130	NA	11
Wall Insulation	49	41	83

* All savings based on January to December 2016 weather data.
Source: Navigant analysis

Table 3-4 shows the comparisons between each method. The average researched savings are the average savings across the simulation modeling and billing analysis results. With the exception of basement insulation, the simulation modeling results are lower than the billing analysis point estimates for all measures. Apart from air sealing and ceiling/attic insulation together, the simulation modeling results are within the confidence bounds of the billing analysis. Except for basement insulation and air sealing and ceiling/attic insulation together, the billing analysis and the simulation modeling results are directionally the same compared to the TRM algorithm estimates, meaning that they are either both higher or both lower than the TRM estimate. Both the billing analysis and simulation modeling predict higher electric savings than the TRM for ceiling/attic insulation, and lower savings than the TRM for air sealing and wall insulation. For basement insulation, simulation modeling predicted higher savings than the TRM and the billing analysis predicted negative savings. However, the billing analysis sample size was only 30 participants for this measure. The billing analysis predicted much higher savings than the TRM for floor insulation. Although Navigant did not calibrate simulation models with crawlspaces, a test run with the floor insulation measure characteristics for billing analysis participants generated savings in the range of only three to seven kWh, or about 30% to 60% of the TRM values.

Table 3-4. Electric Savings Comparison

Measure	Simulation Modeling / Billing Analysis Ratio	Simulation Modeling / TRM Ratio	Billing Analysis / TRM Ratio	Average Researched Savings / TRM Savings
Air Sealing – Blower Door Algorithm	0.5	0.4	0.8	0.6
Ceiling/Attic Insulation	0.5	1.5	2.9	2.2
Air Sealing & Ceiling/Attic Insulation together	0.5	0.6	1.3	1.0
Basement Insulation	-0.5	1.1	-2.2	-0.5
Floor Insulation Above Crawlspace	NA	NA	11.5	11.5
Wall Insulation	0.8	0.5	0.6	0.5

Source: Navigant analysis

3.2 Natural Gas Savings

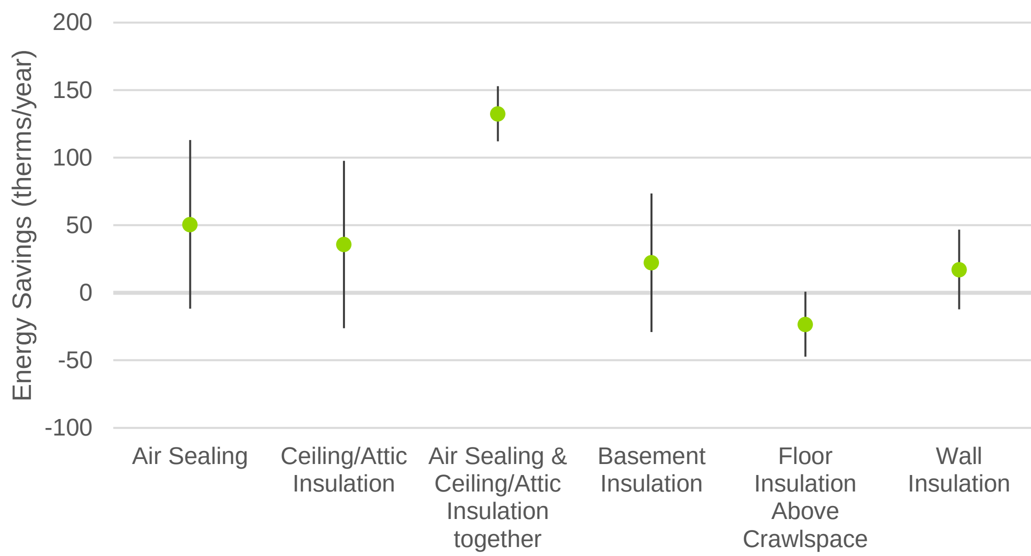
Table 3-5 summarizes the natural gas billing analysis results for the shell end use measures based on calendar year 2016 weather data.[25] As shown by the confidence interval and relative precision, none of the individual measure estimates are statistically significant at 90% confidence. To further illustrate the uncertainty, Figure 3-2 shows the 90% confidence interval for each measure. For the most precise measure, the confidence interval spans over 40 therms per year. We also show air sealing and ceiling/attic insulation together for which the relative precision is much lower leading to a much tighter confidence interval.

Table 3-5. Billing Analysis Natural Gas Savings

Measure	Number of Participants	Energy Savings (therms/year) [90% Confidence Interval]	Relative Precision at 90% Confidence
Air Sealing	1,942	51 [-12, 113]	123%
Ceiling/Attic Insulation	1,938	36 [-26, 98]	173%
Air Sealing & Ceiling/Attic Insulation together	1,938	132 [112, 153]	15%
Basement Insulation	35	22 [-29, 74]	230%
Floor Insulation Above Crawlspace	286	-23 [-47, 1]	103%
Wall Insulation	160	17 [-12, 47]	172%

Source: Navigant analysis

Figure 3-2. Billing Analysis Gas Savings with 90% Confidence Intervals



Source: Navigant analysis

[25] For additional context, in percentage terms the absolute annual savings ranged from 1.8% to 4.7%. It is not uncommon to need very large sample sizes to achieve 90% statistical significance for savings of this magnitude. See Section 3.3 for more context on the customer counts we predict would achieve 90% statistical significance.

Table 3-6 shows the average measure characteristics for the gas billing analysis participants.

Table 3-6. Natural Gas Billing Analysis Participants

Measure	Number of Participants	Average Insulation Area (square feet)	Pre-Retrofit R-Value	Post-Retrofit R-Value	Average Infiltration Reduction (CFM)	Pre-Retrofit CFM	Post-Retrofit CFM
Air Sealing	1,942	NA	NA	NA	1,090	3,678	2,588
Ceiling/Attic Insulation	1,938	1,277	14.3	44.3	NA	NA	NA
Basement Insulation	35	356	5.0	14.8	NA	NA	NA
Floor Insulation Above Crawlspace	286	122	4.8	10.6	NA	NA	NA
Wall Insulation	160	551	4.9	16.7	NA	NA	NA

Source: Navigant analysis

Table 3-7 summarizes the natural gas billing analysis results, simulation modeling results, and TRM algorithm results for the insulation and air sealing measures. Navigant estimated both the simulation modeling results and the TRM algorithm results using 2016 weather data and the measure characteristics shown in Table 3-6 to ensure an apples-to-apples comparison with the billing analysis results. The team was not able to estimate savings for floor insulation in the simulation modeling because there were not enough participants who met the criteria needed for inclusion in the model. Appendix A shows the TRM algorithms and key inputs. Navigant used the blower door test algorithm to calculate TRM air sealing savings because the ComEd and Nicor Gas air sealing programs use pre- and post-retrofit CFM50 values from blower door tests to calculate savings.

Table 3-7. Evaluated Natural Gas Savings*

Measure	Billing Analysis Savings (therms/year)	Simulation Modeling Savings (therms/year)	TRM Algorithm Savings (therms/year)
Air Sealing – Blower Door Algorithm	51	125	99
Ceiling/Attic Insulation	36	66	54
Air Sealing & Ceiling/Attic Insulation together	132	191	153
Basement Insulation	22	10	21
Floor Insulation Above Crawlspace	-23	NA	7
Wall Insulation	17	28	57

* All savings based on January to December 2016 weather data.
Source: Navigant analysis

Table 3-8 shows the comparisons between each method. The average researched savings are the average savings across the simulation modeling and billing analysis results. With the exception of basement insulation, the simulation modeling results are higher than the billing analysis point estimates for all measures. Apart from air sealing and ceiling/attic insulation and air sealing together, the simulation modeling results are within the confidence bounds of the billing analysis. For wall insulation, the results of the two methods were directionally the same compared to the TRM algorithm estimates, while for the other measures the results of the two methods were on opposite sides of the TRM estimate. For air sealing and ceiling/attic insulation, simulation modeling predicted higher savings than the TRM while the billing analysis predicted lower savings. For basement insulation, simulation modeling predicted lower savings than the TRM and the billing analysis predicted higher savings. The billing analysis predicted negative savings for floor insulation. Although Navigant did not calibrate simulation models with crawlspaces, a test run with the floor insulation measure characteristics for billing analysis participants generated savings in the range of only two to five therms, or about 40% to 70% of the TRM values.

Table 3-8. Natural Gas Savings Comparison

Measure	Simulation Modeling / Billing Analysis Ratio	Simulation Modeling / TRM Ratio	Billing Analysis / TRM Ratio	Average Researched Savings / TRM Savings
Air Sealing – Blower Door Algorithm	2.5	1.3	0.5	0.9
Ceiling/Attic Insulation	1.9	1.2	0.7	1.0
Air Sealing & Ceiling/Attic Insulation together	1.4	1.3	0.9	1.1
Basement Insulation	0.4	0.5	1.1	0.8
Floor Insulation Above Crawlspace	NA	NA	-3.3	-3.3
Wall Insulation	1.6	0.5	0.3	0.4

Source: Navigant analysis

Navigant also adjusted the savings for the Air Sealing and Ceiling/Attic Insulation together values to account for efficient lighting installations. Across all accounts with overlap between the billing analysis and efficient lighting installs, Navigant calculated an average heating penalty of 9.1 therms. This value was multiplied by 34% to account for the fact that only 34% of the sample had overlap between these measures, resulting in an average per customer heating penalty of 3.1 therms for the entire billing analysis sample. Based on this, when creating recommended adjustment factors for the IL TRM, Navigant used a savings value of 135.1 therms for the Air Sealing and Ceiling/Attic Insulation together measure (132 therms + 3.1 therms = 135.1 therms).

3.3 Power Analysis

Navigant used a power analysis to estimate how many participants would be needed in each measure to get 90% statistically significant estimates from a billing analysis. Table 3-9 shows estimates for gas and electric participation for each measure rounded to the nearest 500, unless the estimate was below 500 in which case we rounded to the nearest 100. These results give an indication of the sample sizes we would want to have before running a similar analysis again to achieve more precise results.

Table 3-9. Predicted Participant Counts for Statistical Significance

Measure	Billing Analysis	
	Electric	Gas
Air Sealing	7,500	3,000
Ceiling/Attic Insulation	6,000	5,000
Basement Insulation	1,500	200
Floor Insulation Above Crawlspace	4,500	1,500
Wall Insulation	8,500	400

Source: Navigant analysis

4. Recommendations for TRM Updates

With the exception of air sealing and ceiling/attic insulation combined, the billing analysis did not result in statistically significant savings estimates and had a high level of uncertainty. For air sealing and ceiling/attic insulation combined, Navigant recommends using the billing analysis results to update the current cooling and heating adjustment factors in the TRM.[26] For all other measures, Navigant has agreed not to recommend changes to the TRM at this time as stakeholders feel further research is needed to understand the differences between the TRM algorithms and the building simulation modeling used by Navigant. The adjustment factors are included in the TRM algorithms to account for prescriptive engineering algorithms over or under claiming savings.

Table 4-1 shows the current adjustment factors and the recommended adjustment factors for air sealing and ceiling/attic insulation based on the ratio of the billing analysis savings to the TRM savings The TRM algorithm savings include the current heating and cooling adjustment factors in the TRM. The recommended gas heating adjustment factor is the ratio of the analysis savings after adjusting for efficient lighting to the TRM savings after applying the current heating adjustment factor.[27] However, the electric cooling and heating adjustment factors require an additional adjustment to the ratio because the analysis results are overall kWh savings from cooling and heating but the TRM adjustment factor only applies to cooling kWh savings. The cooling and heating adjustment factors are based only on the cooling and heating kWh savings, respectively.

A hyphen, "-", in the table indicates a case where we recommend no change to the current TRM adjustment factor. Navigant recommends one heating and adjustment factor and one cooling adjustment factor for air sealing and ceiling/attic insulation combined because these measures are almost always installed together. For cases where air sealing is completed without attic insulation, Navigant is recommending a 100% adjustment factor, which ultimately results in no change in savings with the existing algorithm. Since this study did not look specifically at savings for electrically heated homes, Navigant is not recommended a change to the electric heating adjustment factor. Navigant recommends no change to the air sealing prescriptive infiltration reduction algorithm because the results of this research are based on pre- and post-retrofit CFM50 values from blower door tests. The blower door

[26] For the heating adjustment factor an adjustment was made to the billing analysis results before creating the recommended TRM adjustment factor to account for efficient lighting. For details see Sections 2.1.3 and 3.2.
[27] For example, for air sealing & ceiling/attic insulation together, the recommended heating adjustment factor is (132 therms + 3.1 therms) / (99 therms / 100% + 54 therms / 60%) = 72%.

algorithm is the primary air sealing savings algorithm in the TRM and the prescriptive infiltration reduction algorithm should only be used if a blower door test is not possible (e.g. large multifamily buildings).

Table 4-1. Current and Recommended Adjustment Factors based on Billing Analysis

Measure	Cooling Adjustment Factor		Heating Adjustment Factor - Therms		Heating Adjustment Factor - kWh	
	Current	Recommended	Current	Recommended	Current	Recommended
Air Sealing – Blower Door Algorithm	None Applied	100%	None Applied	100%	None Applied	100%
Air Sealing – Prescriptive Algorithm	NA*	NA	80%	-†	80%	-
Air Sealing & Ceiling/Attic Insulation together	None Applied & 80%	121%	None Applied & 60%	72%	None Applied	107%

* The TRM does not quantify cooling savings using the prescriptive algorithm.
† A hyphen, "-", in the table indicates a case where we recommend no change to the current TRM adjustment factor.
Source: Navigant analysis

5. Appendix A. TRM Algorithms

Navigant used the average measure characteristics for the billing analysis sample as inputs to the TRM algorithms. The team also used heating and cooling degree days for 2016 to compare the results to the billing analysis and simulation modeling results.

5.1 Air Sealing

Navigant used the blower door test methodology from the TRM to calculate gas and electric savings. Equation 5-1 shows the savings algorithm and Table 5-1 shows the input variables, values, and sources.

Equation 5-1. Air Sealing Savings Algorithm

$$\Delta kWh = \Delta kWh_{cooling} + \Delta kWh_{heating}$$

$$\Delta kWh_{cooling} = \frac{\frac{CFM50_{existing} - CFM50_{new}}{N_{cool}} * 60 * 24 * CDD * DUA * 0.018}{1000 * \eta_{Cool}} * LM$$

$$\Delta kWh_{heating} = \Delta Therms * F_e * 29.3$$

$$\Delta Therms = \frac{\frac{CFM50_{existing} - CFM50_{new}}{N_{heat}} * 60 * 24 * HDD * 0.018}{\eta_{Heat} * 100{,}000}$$

Table 5-1. Air Sealing Variables, Values, and Sources

Variable	Description	Electric Analysis Value	Gas Analysis Value	Source
$CFM50_{existing}$	Infiltration at 50 pascals as measured by blower door before air sealing	4,111	3,678	ComEd and Nicor Gas program tracking data
$CFM50_{new}$	Infiltration at 50 pascals as measured by blower door after air sealing	2,662	2,588	ComEd and Nicor Gas program tracking data
N_{cool}	Conversion factor from leakage at 50 pascals to leakage at natural conditions	38.9 (one story); 31.6 (two story)	38.9 (one story); 31.6 (two story)	Illinois TRM Version 6.0
CDD	Cooling Degree Days	1,237	1,237	degreedays.net (2016 – Chicago O'Hare airport, base temperature 65°F)
DUA	Discretionary Use Adjustment	0.75	0.75	Illinois TRM Version 6.0
η_{Cool}	Efficiency (SEER) of air conditioning equipment	11.9	11.8	ComEd and Nicor Gas program tracking data
LM	Latent Multiplier to account for latent cooling demand	3.2	3.2	Illinois TRM Version 6.0
F_e	Furnace fan energy consumption as a percentage of annual fuel consumption	3.14%	3.14%	Illinois TRM Version 6.0
29.3	kWh per therm	29.3	29.3	Illinois TRM Version 6.0
N_{heat}	Conversion factor from leakage at 50 pascals to leakage at natural conditions	23.9 (one story); 19.4 (two story)	23.9 (one story); 19.4 (two story)	Illinois TRM Version 6.0
HDD	Heating Degree Days	4,696	4,696	degreedays.net (2016 – Chicago O'Hare airport, base temperature 60°F)
η_{Heat}	Efficiency of heating system (nameplate efficiency of 83% derated by 15% for distribution losses)	71%	71%	ComEd and Nicor Gas program tracking data (nameplate efficiency); Illinois TRM Version 6.0 (15% derate)

5.2 Basement Sidewall Insulation

Equation 5-2 shows the savings algorithm and Table 5-2 shows the input variables, values, and sources.

Equation 5-2. Basement Sidewall Savings Algorithm

$$\Delta kWh = \Delta kWh_{cooling} + \Delta kWh_{heating}$$

$$\Delta kWh_{cooling} = \frac{\left(\frac{1}{R_{old\ AG}} - \frac{1}{R_{new}}\right) * A_{basement\ wall\ AG} * (1 - FF) * 24 * CDD * DUA}{1000 * \eta_{Cool}} * ADJ_{BasementCool}$$

$$\Delta kWh_{heating} = \Delta Therms * F_e * 29.3$$

$$\Delta Therms = \frac{\left[\left(\frac{1}{R_{old}} - \frac{1}{R_{new}}\right) * A_{basement\ wall\ AG} * (1 - FF) + \left(\frac{1}{R_{old} + R_g} - \frac{1}{R_{new} + R_g}\right) * A_{basement\ wall\ BG} * (1 - FF)\right] * 24 * HDD}{1000 * \eta_{Heat}} * ADJ_{BasementHeat}$$

Table 5-2. Basement Sidewall Insulation Variables, Values, and Sources

Variable	Description	Electric Analysis Value	Gas Analysis Value	Source
R_{old}	R-value of pre-retrofit foundation wall	5.0	5.0	ComEd and Nicor Gas program tracking data
R_{new}	R-value of post-retrofit foundation wall	15.5	14.8	ComEd and Nicor Gas program tracking data
$A_{basement\ wall}$	Area of basement wall insulation	336	356	ComEd and Nicor Gas program tracking data
$A_{basement\ wall\ AG}$	Area of basement wall insulation above grade	182	171	ComEd and Nicor Gas program tracking data
$A_{basement\ wall\ BG}$	Area of basement wall insulation below grade	154	185	ComEd and Nicor Gas program tracking data
FF	Adjustment to account for area of framing when cavity insulation is used	0%	0%	Illinois TRM Version 6.0
CDD	Cooling Degree Days Conditioned	1,237	1,237	degreedays.net (2016 – Chicago O'Hare airport, base temperature 65°F)
CDD	Cooling Degree Days Unconditioned	321	321	degreedays.net (2016 – Chicago O'Hare airport, base temperature 75°F)
DUA	Discretionary Use Adjustment	0.75	0.75	Illinois TRM Version 6.0
η_{Cool}	Efficiency (SEER) of air conditioning equipment	11.9	11.8	ComEd and Nicor Gas program tracking data
1000	Converts Btu to kBtu	1000	1000	Illinois TRM Version 6.0
$ADJ_{BasementCool}$	Adjustment to account for prescriptive engineering algorithms overclaiming savings	80%	80%	Illinois TRM Version 6.0
F_e	Furnace fan energy consumption as a percentage of annual fuel consumption	3.14%	3.14%	Illinois TRM Version 6.0
29.3	kWh per therm	29.3	29.3	Illinois TRM Version 6.0

Variable	Description	Electric Analysis Value	Gas Analysis Value	Source
HDD	Heating Degree Days Conditioned	4,696	4,696	degreedays.net (2016 – Chicago O'Hare airport, base temperature 60°F)
HDD	Heating Degree Days Unconditioned	2,811	2,811	degreedays.net (2016 – Chicago O'Hare airport, base temperature 50°F)
η_{Heat}	Efficiency of heating system (nameplate efficiency of 83% derated by 15% for distribution losses)	71%	71%	ComEd and Nicor Gas program tracking data (nameplate efficiency); Illinois TRM Version 6.0 (15% derate)
$ADJ_{BasementHeat}$	Adjustment to account for prescriptive engineering algorithms overclaiming savings	60%	60%	Illinois TRM Version 6.0

5.3 Floor Insulation Above Crawlspace

Equation 5-3 shows the savings algorithm and Table 5-3 shows the input variables, values, and sources.

Equation 5-3. Floor Insulation Savings Algorithm

$$\Delta kWh = \Delta kWh_{cooling} + \Delta kWh_{heating}$$

$$\Delta kWh_{cooling} = \frac{\left(\frac{1}{R_{old}} - \frac{1}{R_{new}}\right) * Area * (1 - FF) * 24 * CDD * DUA}{1000 * \eta_{Cool}} * ADJ_{FloorCool}$$

$$\Delta kWh_{heating} = \Delta Therms * F_e * 29.3$$

$$\Delta Therms = \frac{\left(\frac{1}{R_{old}} - \frac{1}{R_{new}}\right) * Area * (1 - FF) * 24 * HDD}{1000 * \eta_{Heat}} * ADJ_{FloorHeat}$$

Table 5-3. Floor Insulation Variables, Values, and Sources

Variable	Description	Electric Analysis Value	Gas Analysis Value	Source
R_{old}	R-value of pre-retrofit floor insulation	4.9	4.8	ComEd and Nicor Gas program tracking data
R_{new}	R-value of post-retrofit floor insulation	10.5	10.6	ComEd and Nicor Gas program tracking data
Area	Total floor area insulated	129	122	ComEd and Nicor Gas program tracking data
FF	Adjustment to account for area of framing	12%	12%	Illinois TRM Version 6.0
24	Converts hours to days	24	24	Illinois TRM Version 6.0

Variable	Description	Electric Analysis Value	Gas Analysis Value	Source
CDD	Cooling Degree Days	321	321	degreedays.net (2016 – Chicago O'Hare airport, base temperature 75°F)
DUA	Discretionary Use Adjustment	0.75	0.75	Illinois TRM Version 6.0
η_{Cool}	Efficiency (SEER) of air conditioning equipment	11.9	11.8	ComEd and Nicor Gas program tracking data
1000	Converts Btu to kBtu	1000	1000	Illinois TRM Version 6.0
$ADJ_{FloorCool}$	Adjustment to account for prescriptive engineering algorithms overclaiming savings	80%	80%	Illinois TRM Version 6.0
F_e	Furnace fan energy consumption as a percentage of annual fuel consumption	3.14%	3.14%	Illinois TRM Version 6.0
29.3	kWh per therm	29.3	29.3	Illinois TRM Version 6.0
HDD	Heating Degree Days	2,811	2,811	degreedays.net (2016 – Chicago O'Hare airport, base temperature 50°F)
η_{Heat}	Efficiency of heating system (nameplate efficiency of 83% derated by 15% for distribution losses)	71%	71%	ComEd and Nicor Gas program tracking data (nameplate efficiency); Illinois TRM Version 6.0 (15% derate)
$ADJ_{FloorHeat}$	Adjustment to account for prescriptive engineering algorithms overclaiming savings	60%	60%	Illinois TRM Version 6.0

5.4 Wall and Ceiling/Attic Insulation

Equation 5-4 shows the savings algorithm and Table 5-4 shows the input variables, values, and sources.

Equation 5-4. Wall and Ceiling/Attic Insulation Savings Algorithm

$$\Delta kWh = \Delta kWh_{cooling} + \Delta kWh_{heating}$$

$$\Delta kWh_{cooling} = \frac{\left(\frac{1}{R_{old}} - \frac{1}{R_{new}}\right) * Area * (1 - FF) * 24 * CDD * DUA}{1000 * \eta_{Cool}} * ADJ_{WallAtticCool}$$

$$\Delta kWh_{heating} = \Delta Therms * F_e * 29.3$$

$$\Delta Therms = \frac{\left(\frac{1}{R_{old}} - \frac{1}{R_{new}}\right) * Area * (1 - FF) * 24 * HDD}{1000 * \eta_{Heat}} * ADJ_{WallAtticHeat}$$

Table 5-4. Wall and Ceiling/Attic Insulation Variables, Values, and Sources

Variable	Description	Electric Analysis Value	Gas Analysis Value	Source
R_{old}	R-value of pre-retrofit ceiling/attic or wall insulation	4.9 (wall); 12.1 (attic)	4.9 (wall); 14.3 (attic)	ComEd and Nicor Gas program tracking data
R_{new}	R-value of post-retrofit ceiling/attic or wall insulation	17.8 (wall); 45.5 (attic)	16.7 (wall); 44.3 (attic)	ComEd and Nicor Gas program tracking data
Area	Total area of insulated wall or ceiling/attic	318 (wall); 959 (attic)	551 (wall); 1,277 (attic)	ComEd and Nicor Gas program tracking data
FF	Adjustment to account for area of framing	25% (wall); 7% (attic)	25% (wall); 7% (attic)	Illinois TRM Version 6.0
24	Converts hours to days	24	24	Illinois TRM Version 6.0
CDD	Cooling Degree Days	1,237	1,237	degreedays.net (2016 – Chicago O'Hare airport, base temperature 65°F)
DUA	Discretionary Use Adjustment	0.75	0.75	Illinois TRM Version 6.0
η_{Cool}	Efficiency (SEER) of air conditioning equipment	11.9	11.8	ComEd and Nicor Gas program tracking data
1000	Converts Btu to kBtu	1000	1000	Illinois TRM Version 6.0
$ADJ_{WallAtticCool}$	Adjustment to account for prescriptive engineering algorithms overclaiming savings	80%	80%	Illinois TRM Version 6.0
F_e	Furnace fan energy consumption as a percentage of annual fuel consumption	3.14%	3.14%	Illinois TRM Version 6.0
29.3	kWh per therm	29.3	29.3	Illinois TRM Version 6.0
HDD	Heating Degree Days	4,696	4,696	degreedays.net (2016 – Chicago O'Hare airport, base temperature 60°F)
η_{Heat}	Efficiency of heating system (nameplate efficiency of 83% derated by 15% for distribution losses)	71%	71%	ComEd and Nicor Gas program tracking data (nameplate efficiency); Illinois TRM Version 6.0 (15% derate)
$ADJ_{WallAtticHeat}$	Adjustment to account for prescriptive engineering algorithms overclaiming savings	60%	60%	Illinois TRM Version 6.0

6. Appendix B. Simulation Modeling Calibration

Navigant disaggregated the pre-retrofit monthly electric and gas consumption totals into end uses for calibration targets using the Navigant billing data end use disaggregation tool. This tool is Navigant's standard practice and has been used for numerous residential evaluations.

6.1 Lighting

Annual lighting consumption is based on the 2014 Building America House Simulation Protocols[28], which calculates consumption based on home size:

$$Interior\ Hard\ Wired\ Lighting\ Consumption\ (kWh) = 0.8 * (Floor\ Area\ (sf) * 0.542 + 334)$$
$$Interior\ Plug\ In\ Lighting\ Consumption\ (kWh) = 0.2 * (Floor\ Area\ (sf) * 0.542 + 334)$$
$$Garage\ Lighting\ Consumption\ (kWh) = Garage\ Area\ (sf) * 0.08 + 8$$
$$Exterior\ Lighting\ Consumption\ (kWh) = Floor\ Area\ (sf) * 0.145$$

Next, the tool breaks the annual consumption into monthly values using a seasonal load profile derived from a CFL monitoring study conducted for the California investor-owned utilities (IOUs).[29] This load profile accounts for the fact that lighting use increases in the winter when there is less daylight. The tool calculates average monthly lighting electricity consumption by multiplying the lighting profile by the annual lighting consumption estimate.

6.2 Hot Water

Hot water consumption is based on Building America Benchmark hot water end use profiles. The Building America profiles include the average daily hot water consumption used each month for the dishwasher, clothes washer, baths, showers, and sinks, as well as the average temperature of the water mains. The tool calculates the monthly gas consumption using the total monthly hot water consumption and the seasonally adjusted water mains temperature. The monthly consumption includes the water heating load and the standby heat loss load:

$$Water\ Heating\ Load\ \left(\frac{therms}{day}\right) = Consumption\ \left(\frac{gal}{day}\right) * 8.33\left(\frac{Btu}{gal\ °F}\right) * \frac{Water\ Temp - Mains\ Temp\ (°F)}{Heating\ Efficiency * 100{,}000\ Btu/therm}$$

$$Heat\ Loss\ Load\ \left(\frac{therms}{day}\right) = Tank\ UA\left(\frac{Btu}{hr\ °F}\right) * \frac{(Water\ Temp - Mains\ Temp\ (°F)) * 24\ hr/day}{Heating\ Efficiency * 100{,}000\ Btu/therm}$$

6.3 Miscellaneous Equipment

After calculating lighting and hot water consumption, the tool calculates the remaining consumption attributable to miscellaneous equipment and HVAC equipment. The tool calculates miscellaneous

[28] National Renewable Energy Laboratory, 2014 Building America House Simulation Protocols: https://www.nrel.gov/docs/fy14osti/60988.pdf
[29] KEMA, Inc. CFL Metering Study, Final Report. Prepared for Pacific Gas and Electric, San Diego Gas and Electric, and Southern California Edison. February 25, 2005.

equipment consumption by determining the base month, which is the month with the lowest remaining consumption per day, assuming the HVAC consumption accounts for five percent of the base month total. The tool subtracts the HVAC consumption in the base month from the remaining consumption and assumes that miscellaneous equipment consumption is constant throughout the year.

6.4 HVAC Equipment

The tool splits the remaining consumption attributable to HVAC equipment into heating and cooling consumption by assigned all winter season consumption (November through March) to heating and all summer season consumption (June through August) to cooling. The tool splits the shoulder season HVAC consumption into heating and cooling by assuming the split is proportional to the Heating Degree Days (HDDs) and Cooling Degree Days (CDDs) in each month.