NAVIGANT

Energy Efficiency / Demand Response Nicor Gas Plan Year 1 (6/1/2011-5/31/2012)

Research Report: Furnace Metering Study

FINAL

Presented to
Nicor Gas Company

August 1, 2013

Prepared by:
Randy Gunn
Managing Director
Navigant Consulting
30 S. Wacker Drive, Suite 3100
Chicago, IL 60606

Phone 312.583.5700
Fax 312.583.5701

www.navigantconsulting.com

NAVIGANT

Submitted to:
Nicor Gas
1844 Ferry Road
Naperville, IL 60563

Submitted by:
Navigant Consulting, Inc.
30 S. Wacker Drive, Suite 3100
Chicago, IL 60606
Phone 312.583.5700
Fax 312.583.5701

Contact:
Randy Gunn, Managing Director
312.938.4242
randy.gunn@navigant.com

Julianne Meurice, Associate Director
312.583.5740
julianne.meurice@navigant.com

Prepared by:
Laura Tabor, Senior Consultant
Navigant Consulting
303.728.2470
laura.tabor@navigant.com

Tim Stanton, Senior Consultant
Navigant Consulting
312.583.2722
tim.stanton@navigant.com

NAVIGANT

Table of Contents

List of Figures and Tables

Figures:

Tables:

E. Executive Summary

This research study sought to quantify the natural gas heating load, equivalent full load hours (EFLH) and associated natural gas savings for high-efficiency residential gas furnaces in the Nicor Gas service territory.

E.1 Research Methods

Navigant analyzed participant billing data, metered field data, and a calibrated energy model to refine estimates of average heating loads for Nicor Gas Home Energy Efficient Rebate (HEER) program participants purchasing high-efficiency furnaces. The analysis team used a nested sampling approach in order to maximize precision while maintaining a manageable number of field sites. The team disaggregated billing data to estimate gas heating loads for a sample of 380 participants. Navigant randomly selected 39 participants from this pool for the on-site sample, where data loggers were installed on the furnaces from November 2012 to May 2013. Navigant calculated the final results using the average ratio of metered results to billing data disaggregation results from the on-site sample. The team also used an energy simulation model to extrapolate the final results from the 2012 – 2013 heating season to a typical weather year.

E.2 Research Results

This study found that the average HEER participant who purchased a new high-efficiency furnace had an average heating load of 834 therms annually. Using this heating load with the Illinois Technical Reference Manual (TRM) baseline of 80% AFUE and average installed efficiency of 95.1% results in annual natural gas savings of 166 therms. Table E-1 compares these results to the Illinois TRM default values for the Chicago area.

Table E-1. Final Furnace Study Results

Metric	Research Result	Current TRM Value[1]
Average Heating Load (therms)	834	806
Average EFLH (hours)	976	n/a
Average Savings (therms)[2]	166	160

E.3 Findings and Recommendations

Navigant offers the following findings and recommendations to Nicor Gas from this study:

Finding. The primary finding from this research is that the metered data showed higher gas heating loads for Nicor Gas HEER participants than previous work estimated. The heating loads and associated savings from this study exceed both the Rider 29 evaluation estimates and the current values in the Illinois TRM for the Chicago area.

[1] TRM heating load for the Chicago area. Nicor Gas participants are predominantly in this climate zone, but there are some in the Rockford zone (as defined by the TRM) as well.

[2] Based on TRM baseline of 80% AFUE and installed AFUE of 95%

Recommendation. Navigant recommends that Nicor Gas adopt the use of this territory-specific heating load estimate in determining deemed savings estimates for high efficiency furnaces moving forward.

Recommendation. Navigant recommends that future versions of the Illinois TRM incorporate the results of this research.

Finding. Navigant observed that three of the 39 on-site participants had purchased two new furnaces through the program. Several other on-site homes also had second furnaces of varying ages and levels of use. Since Navigant sampled at the furnace level and not the home level, these two-furnace homes generally had lower ratios of metered to billed consumption (one furnace metered, but billing data reflects both furnaces).

Recommendation. Nicor Gas may want to consider adding a checkbox for “more than one furnace” or a field for “number of furnaces” to collect additional data on how many furnaces participant homes typically have.

Finding. The good relative precision for the study overall and in particular for the ratio of metered to billed consumption estimates show that the billing data disaggregation analysis provided a strong indicator of actual heating consumption. This means that for this type of research, the double ratio nested sampling approach can be an efficient means of providing statistically significant results with relatively small on-site samples.

Recommendation. Navigant recommends considering using a similar statistical approach for future field research where appropriate.

1. Study Objectives and Methods

This study focused on several aspects of the gas consumption of high-efficiency natural gas furnaces. The primary goal of the study is to provide refined heating load estimates for residential gas furnaces in the Nicor Gas service territory which may inform future versions of the Illinois Technical Reference Manual (TRM). High-efficiency furnaces are the single largest measure in Nicor Gas' residential portfolio, which warrants a rigorous analysis of their energy savings.

Navigant sought to provide three results: revised natural gas heating load and natural gas savings for homes with high-efficiency natural gas furnaces, as well as an estimate of equivalent full load hours (EFLH).

1.1 Research Methodology

Navigant used a nested sampling approach to maximize the statistical precision of the results. The team disaggregated billing data to calculate preliminary estimates of gas heating load, EFLH and associated savings for a sample of 380 homes.[3] From this larger sample, Navigant randomly selected 39 homes for on-site metering. In the final results, Navigant used double ratio estimation to leverage the ratio of metered gas heating consumption to disaggregation-estimated gas heating consumption for these sites to estimate average gas heating consumption for the entire billing data disaggregation sample.[4]

1.1.1 Sample Selection

Navigant selected the sample by starting with billing data of all homes that installed furnaces of 95% AFUE or higher through the Nicor Gas HEER program during Rider 29. The analysis team filtered the database by removing datasets that were duplicates, contained negative billing data, or showed a change of home ownership from 2009 to 2012. This filtered database was then manipulated to reflect the actual gas consumption per month ("monthly consumption data") rather than the billed therms per month ("monthly billed data") based on the billing cycle date. The evaluation team visually analyzed the remaining datasets to ensure an accurate reflection of gas consumption per month (e.g. datasets were removed if they had very erratic load shapes). After Navigant applied these filtering techniques to the original database, the team randomly selected 380 monthly consumption datasets to perform the analysis. Navigant used this sample to recruit on-site participants, ensuring that all on-site participants would also be in the billing data analysis.

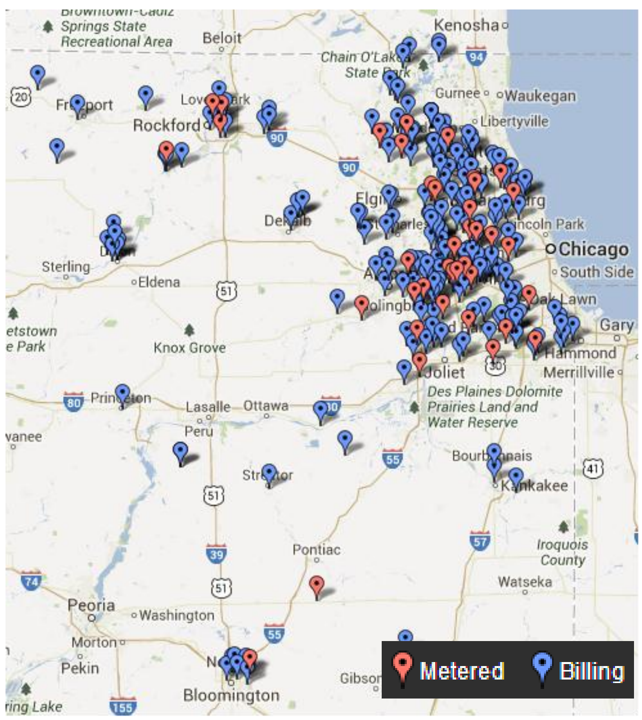
[3] Although preliminary results reported in the GPY1 HEER report indicated a slightly larger sample, a few participants showed null billing records for 2012-2013. This indicated that participants may have moved and these records were removed from the analysis.
[4] For additional description of double ratio estimation, see: Wright, R.L. et al. "Double Ratio Analysis: A New Tool for Cost-Effective Monitoring." ACEEE, 1994.

Table 1-1. Sample Selection Process

Analysis Stage	N
Nicor Gas Rider 29 ≥95% AFUE Furnace Participants	19,052
Participant Billing Data Provided	800
Remaining Sample After Filtering	665
Billing Data Sample Selected[5]	380
On-site Sample Selected	39

Navigant did not stratify the sample or use formal representativeness quotas. The majority of the final metering sites were in the suburbs of Chicago with some in the Rockford area to the northwest and the Bloomington area to the southwest. Figure 1-1 shows the distribution of the overall billing data and metered samples.[6]

Figure 1-1: Map of Billing Data and Metered Samples



Source: Navigant analysis, BatchGeo.com

---

[5] Navigant kept participants with modulating furnaces in the billing data sample, but did not include these in the sample frame for the on-sites because they would require a different metering approach.

[6] Due to mapping program limitations, only 250 of the 380 sites are shown on this map. All 39 metered sites are shown.

1.1.2 Billing Data Disaggregation

Navigant used participant billing records and program data on furnace models installed to estimate heating load, EFLH and furnace savings for the 380 participants in the analysis sample. The evaluation team used a sample of Rider 29 participants as suggested by Nicor Gas in order to maximize the amount of billing data available, assuming that this population is similar to Rider 30 participants. For a complete description of the disaggregation methodology, please see Appendix 4.1.

1.1.3 Metering Approach

Navigant installed data loggers in the field on a sample of ≥95% AFUE furnaces in 39 homes in November 2012, leaving the loggers installed until May 2013. In addition to collecting time of use data from both the furnace gas valves and blower motor, Navigant also took spot measurements of furnace gas consumption, monitored indoor temperature at the thermostat at ten minute intervals and collected data on home characteristics. For dual stage furnaces, Navigant metered both gas valves and took spot measurements at both high and low stages whenever possible.[7]

1.1.3.1 Logger Installation Procedures

At each site, Navigant first conducted a brief interview with the homeowner. This interview collected information on home occupancy, physical characteristics of the house and other gas appliances in the household.

After conducting the interview, field staff recorded the gas meter number and current meter reading and proceeded to install the data loggers at the furnace. Navigant installed a current transducer (CT) on each solenoid gas valve wire and on the blower motor wire. Each current transducer was connected to a data logger which recorded an on or off state based on the presence or absence of current in each wire. Figure 1-2 shows two CTs installed on the solenoid valve wires of a dual stage furnace; the inset shows an example of the data loggers to which each CT connects.

[7] Some dual stage furnaces are hardwired to operate in one stage only, or may be programmed in such a way that getting the high stage to fire in moderate weather is not feasible (and trying could cause participants discomfort).

Figure 1-2: Example Installation of Current Transducers on Dual Stage Furnace

To take spot measurements of gas consumption, field staff ensured that all other gas equipment was turned off and recorded the gas consumption on the meter for a fixed period of time with the furnace on. Navigant repeated this procedure for both low and high stage for dual stage units. Field staff also installed a temperature logger near the thermostat controlling the furnace.

Finally, Navigant conducted a physical inspection of the home to determine approximate floor, wall and window areas as well as wall and window types.

1.1.3.2 Combustion Efficiency Spot Measurements

Navigant also attempted to take spot measurements of furnace combustion efficiency during the logger installation visits. Due to equipment malfunction, the field team was unable to collect reliable data from all sites. Navigant addressed these equipment issues and planned to re-take these measurements during the retrieval visits, but on most of these visits the weather was too hot to force the furnace to fire without making participants' homes uncomfortably warm. The sites with reasonable data did show lower spot measurements than the units' rated AFUE, but given the small number of reasonable measurements and the fact that the team could only measure once when the unit had only been running for five to ten minutes, Navigant elected to use rated AFUE values for both baseline and efficient equipment to calculate heat loads and savings from the consumption data.

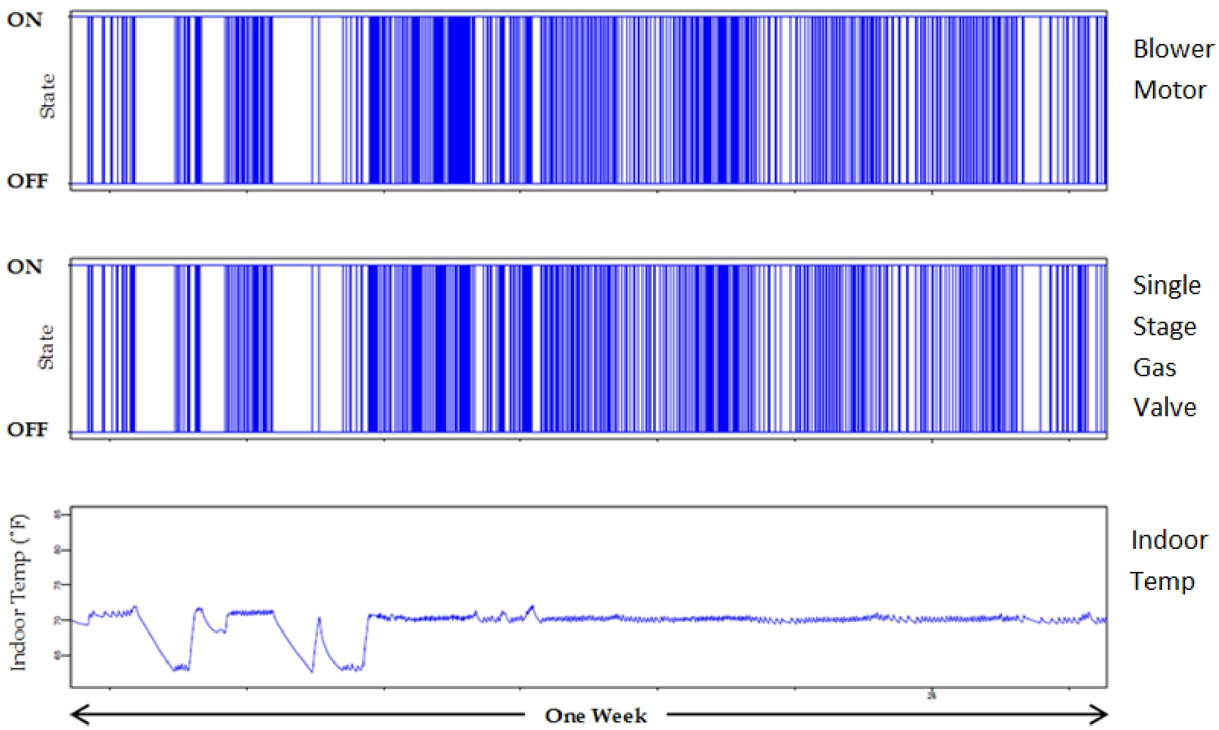
1.1.3.3 Metered Data Analysis

After retrieving the data loggers, Navigant first analyzed the logger data for quality. The team constructed histograms of time between state changes to identify "flicker"[8] in each logger file and applied flicker filters to reflect the actual operation of the furnace. For additional detail on flicker filters and other

[8] "Flicker" occurs when the data logger quickly oscillates between the "on" state and "off" state without characterizing the true operation of the furnace.

quality control procedures, please see Appendix 4.2.1: Data QC and Cleaning. Navigant also generated weekly, monthly, and seasonal graphs to ensure the blower motor operation, gas valve operation, and indoor temperature data was logical. Figure 1-3 shows an example of these weekly graphs. In this particular case Navigant determined the dataset to be reasonable based on matching blower (top) and single stage gas valve operation (middle) and the temperature setbacks (bottom) which correlated well with lack of furnace operation.

Figure 1-3: Example Weekly Furnace Operation Graphs



The evaluation team then removed all data on and before the installation date and on and after the retrieval date and converted the filtered logger data into percent "on" per hour for the logging time period. For dual stage furnaces, because the low stage logger was also "on" when the furnace ran in high stage, Navigant subtracted the high stage operation time from the low stage operation time to determine the actual low stage operation time per hour. Navigant then converted the run time in each stage to actual gas consumption using the gas consumption spot measurements and Nicor Gas' BTU Ratio.[9]

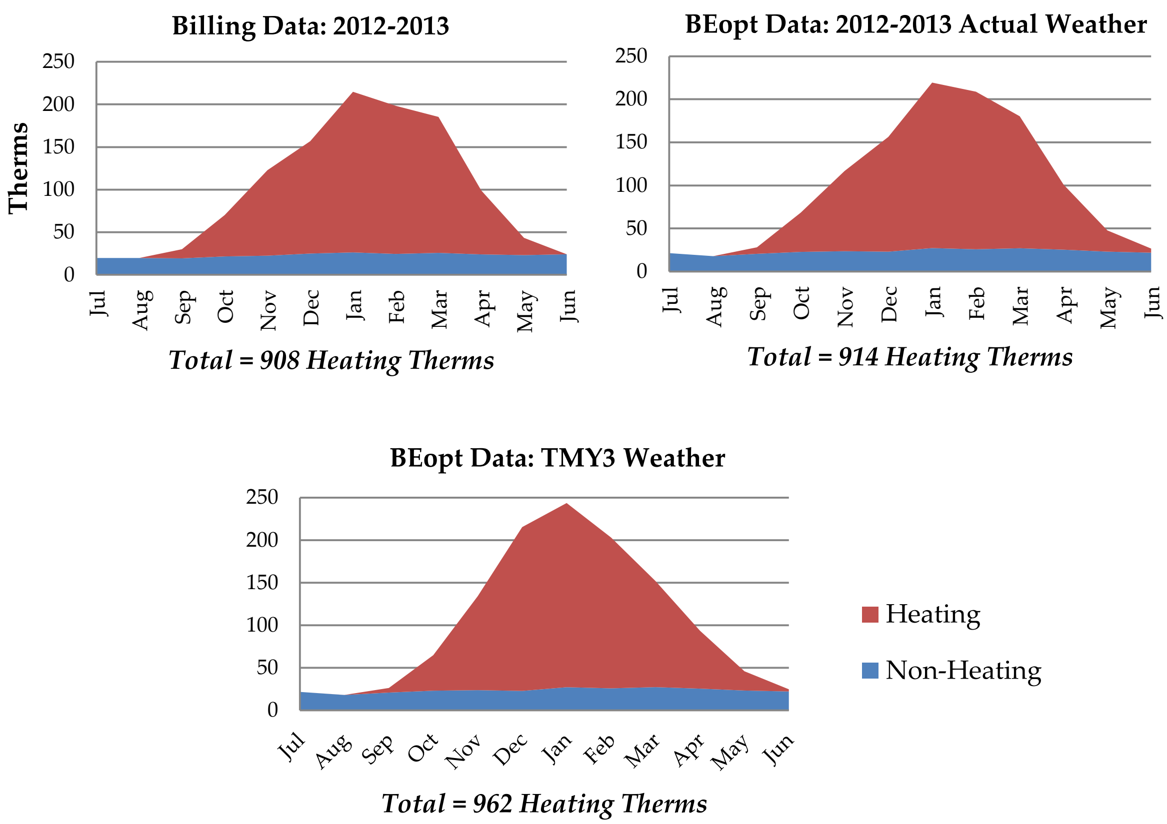
1.1.4 Energy Model Development and Calibration

Navigant used home characteristics details collected from the on-site sample to build an energy model in the Building Energy Optimization (BEopt) software developed by the National Renewable Energy Laboratory (NREL).[10] The purpose of the model was to more accurately extrapolate the billing data from the 2012-2013 heating season to a typical weather year. Navigant first built the model based on homes in the study and calibrated it such that the output aligned with the average consumption from the

[9] The BTU ratio is a conversion factor for converting CCF to BTUs. This ratio varies seasonally and geographically. Navigant used a weighted average BTU ratio of 1.0137 CCF/BTU based on 2011 data from Nicor Gas.
[10] Navigant used the EnergyPlus engine with the BEopt software. EnergyPlus was also developed by NREL.

participant billing records when run with actual weather data from the recent heating season (to a difference of less than one percent).[11] Once the model was sufficiently calibrated, the analysis team ran the model using a Typical Meteorological Year (TMY3) file from Chicago. TMY3 data represents typical weather patterns for the location. As shown in Figure 1-4, the shapes of the billing and modeled data sets are slightly different, but for the actual weather comparison the heating season totals differ by only 0.6% overall. The higher value of the TMY3 model output indicates that 2012-2013 was a warmer than average winter with lower heating usage.

Figure 1-4: Comparison of Heating and Total Therms Between Billing and Modeled Data



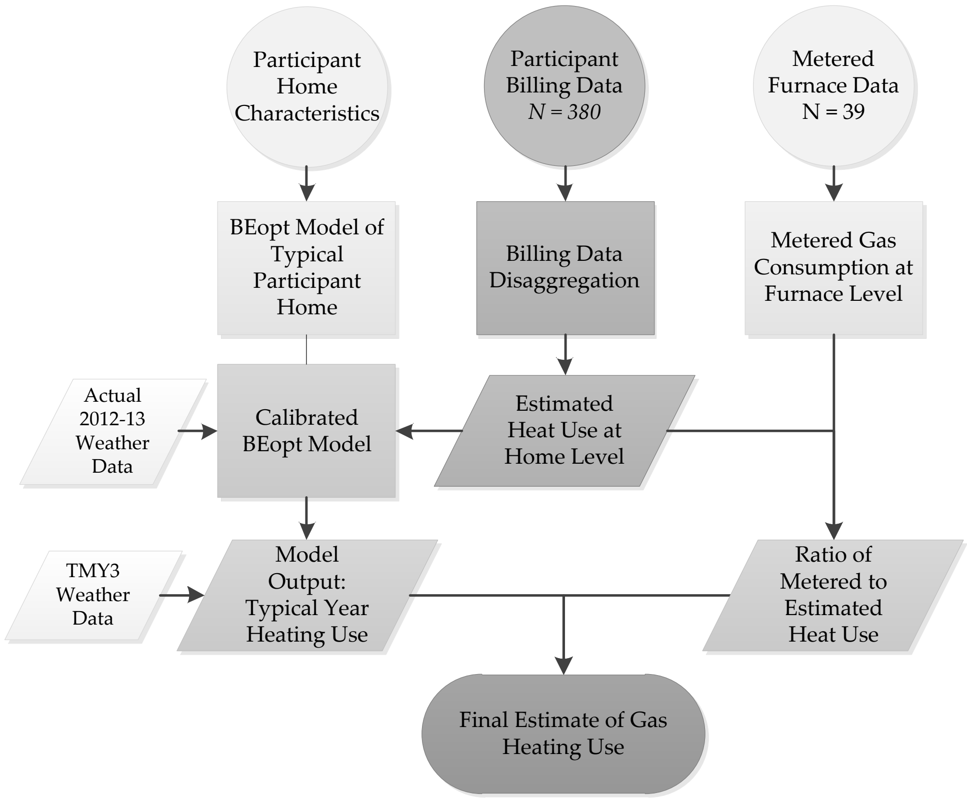
1.1.5 Calculation of Final Results

Figure 1-5 illustrates the flow of data from each portion of the analysis into the final results. The final estimate of gas heating consumption is the product of the typical year heating use (output from calibrated model) and the calculated ratio of the metered furnace heating use and billing data disaggregation heating use estimates. This ratio was calculated using data from the five full months spanned by the metering period (December 2012 through April 2013).[12]

[11] Navigant used an actual weather file from Chicago O'Hare airport for July 2012 – June 2013 to calibrate the model. The TMY3 file was also for Chicago O'Hare. The TMY3 file reflects the average weather from 1991 to 2005 at a given location.

[12] Navigant installed loggers during the month of November 2012 and removed them during May 2013. In order to compare to monthly billing data, Navigant limited the metered-to-billing ratio calculation to the months with complete data.

Figure 1-5: Illustration of Results Roll-up



Navigant then calculated site-level heating loads by multiplying the final estimates of heat use for each home by its rated furnace AFUE.

2. Research Results

Table 2-1. Final Results and Statistics

shows the final results of the study for gas heating load and therm savings. The team achieved an overall relative precision of 7.7% at 90% confidence using the double-ratio approach.[13] These final results yielded average savings of 166 therms given a baseline of 80% AFUE and average rated AFUE of 95.1%.

Table 2-1. Final Results and Statistics

Metric	Mean	N	Rel. Precision at 90% Confidence	Description
2012-2013 Heating Load, Billed	854	380	3.5%	Mean of site level 2012-2013 heating therms, multiplied by site AFUE
Ratio of Metered to Billed Use	0.91	39	6.8%	Mean ratio of metered 2012-2013 therm use to disaggregated billing data therm use for the same period
Typical Year Heating Load (Model Extrapolated from Billed)[14]	915	N/A	N/A	Model therm output for a typical weather year, multiplied by weighted average AFUE[15]
Final Estimate of Heating Load	834	N/A	7.7%	Product of typical year heating load therms and mean ratio of metered to billed heating loads

2.1 *Therm Savings and EFLH*

Navigant used the final heating load estimate to calculate average therm savings for Nicor Gas HEER participants using the Illinois TRM algorithm:

$$Average\ Therm\ Savings = Gas\ Heating\ Load\ \times \left(\frac{1}{AFUE_{base}} - \frac{1}{AFUE_{ee}}\right)$$

Where $AFUE_{base}$ is equal to 80% per the TRM and $AFUE_{ee}$ equals 95.1%, the weighted average AFUE of participants in the sample.

Navigant rearranged the following standard equation for furnace therm savings to calculate the weighted average EFLH for the entire sample of 380 participants:

$$Therm\ Savings_i = EFLH_i\ \times Furnace\ Capacity_i \times \left(\frac{1}{AFUE_{base}} - \frac{1}{AFUE_{ee,i}}\right)$$

[13] Wright, R.L. et al. "Double Ratio Analysis: A New Tool for Cost-Effective Monitoring." ACEEE, 1994.
[14] There are no statistical metrics for the step where Navigant extrapolated 2012-2013 data to a typical weather year; this is simply a weather adjustment to provide a result than can be used for annual savings across any given year.
[15] Average installed AFUE, weighted by site consumption

$$Weighted\ Average\ EFLH = \frac{\sum_i Therm\ Savings}{\sum_i Furnace\ Capacity_i \times \left(\frac{1}{AFUE_{base}} - \frac{1}{AFUE_{ee,i}}\right)}$$

Where furnace capacity equals the maximum rated capacity of the unit in Btu, and the sum of therm savings is equal to the number of participants multiplied by the average therm savings previously calculated. Table 2-2. Final Results for Average Therm Savings and EELH

shows the resulting values for average therm savings and EFLH.

Table 2-2. Final Results for Average Therm Savings and EELH

Metric	Research Result
Average Therm Savings	166
Average EFLH	976

2.2 Results Discussion

The study achieved the primary goals of providing estimates of gas heating load, therm savings and EFLH for Nicor Gas HEER participants installing high efficiency furnaces. Navigant also met the statistical target of less than 10% relative precision at 90% confidence with a final relative precision of 7.7%. Navigant describes some of this research's additional strengths and challenges in this section.

2.2.1 Study Strengths and Weaknesses

There are several strengths which demonstrate the reliability of these results:

- Actual run time data for 39 homes provides heating-specific data that is not available from any other method
- Billing data analysis allowed Navigant to leverage a larger sample while keeping on-site costs low. The nested sampling approach also reduced the potential for bias due to the location, size or other characteristics of the metered sites, since the key data output from the metered sites was not their absolute consumption but the ratio of their metered consumption and billing data consumption estimates.
- Use of an energy model to extrapolate values to a typical weather year is more accurate than the simple heating degree-day approach used previously for two reasons: first, the model is able to capture hourly and daily temperature variability instead of simple average temperatures. Second, the model captures other weather effects such as cloud cover (affects solar gains) and wind (affects infiltration) in addition to temperature.

There are some caveats which should be considered when using these results:

- The metered data sample relies on a spot measurement of furnace input capacity. These measurements were all within ten percent of rated values, but may vary slightly during furnace operation.
- The model extrapolation is based only on the known home characteristics of the metered sample and is specific to the Nicor Gas service territory. Other regions with different housing stock, furnace sizing practices or participant behavior may see different results.

- Navigant was unable to effectively verify installed unit operating efficiency, and thus elected to rely on rated AFUE to estimate heating loads and savings from the calculated gas heating consumption.

3. Findings and Recommendations

Navigant offers the following findings and recommendations to Nicor Gas from this study:

Finding. Navigant's analysis showed higher gas heating loads for Nicor Gas HEER participants than previous work estimated. The heating loads and associated savings from this study exceed both the Rider 29 evaluation estimates and the current values in the Illinois TRM for the Chicago area.

> **Recommendation.** Navigant recommends that Nicor Gas adopt the use of this territory-specific heating load estimate in determining deemed savings estimates for high efficiency furnaces moving forward.
>
> **Recommendation.** Navigant recommends that future versions of the Illinois TRM incorporate the results of this research.

Finding. Navigant observed that three of the 39 on-site participants had purchased two new furnaces through the program. Several other on-site homes also had second furnaces of varying ages and levels of use. Since Navigant sampled at the furnace level and not the home level, these two-furnace homes generally had lower ratios of metered to billed consumption (one furnace metered, but billing data reflects both furnaces). This means that the new furnaces in these homes typically consume—and therefore save—less than an average unit installed in a single-furnace home.

> **Recommendation.** Nicor Gas may want to consider adding a checkbox on the program application for "more than one furnace" or a field for "number of furnaces" to collect additional data on how many furnaces participant homes typically have. Navigant was not able to stratify the sample based on number of furnaces since there was no data for the billing analysis-only portion of the sample on number of furnaces. With this information, Nicor Gas could improve its knowledge of how many two-furnace homes are installing new units (and potentially achieving below average savings), and could also improve the ability of future studies to investigate the difference between savings from units installed in one-furnace homes and two-furnace homes.

Finding. The good relative precision for the study overall and in particular for the ratio of metered to billed consumption estimates show that the billing data disaggregation analysis provided a strong indicator of actual heating consumption. This means that for this type of research, the double ratio nested sampling approach can be an efficient means of providing statistically significant results with relatively small on-site samples.

> **Recommendation.** Navigant recommends considering using a similar statistical approach for future field research where appropriate.

4. Appendices

4.1 Disaggregation Methodology

Navigant constructed a disaggregation tool to separate the heating and non-heating portion of the post-installation consumption data using the following steps:

1. Estimate non-heating loads by month using:
    a. Building America inputs (i.e. load shapes and input capacities of non-heating gas appliances)[16]
    b. Installation rates of gas non-heating appliances based on Bass & Company Potential Study[17]
2. Calculate average summer usage based on the mean of participants' July and August gas consumption. July and August usage are most representative of non-heating only consumption.
3. Calibrate the model's non-heating loads to the summer average calculated in Step 2. This step essentially scales the load shape profile to typical summer usage.
4. Calculate the percentage of heating versus non-heating gas consumption for the post-installation data for each month. Since 2013 summer billing data is not yet available, Navigant used 2012 summer averages.
5. Apply the heating percentages by month to each participant's usage to disaggregate the heating portion of the gas consumption data. This calculation is summarized in the following algorithm:

$$HPF_{i,j} = \frac{\frac{\sum_1^k C_{i,j,k}}{k} - C_{i,j,k} * (C_{non-heating})_{i,j}}{\frac{\sum_1^k C_{i,j,k}}{k}}$$

[16] Building America Benchmarking Program Database. U.S. Department of Energy, 2010.

[17] Jacobson, B. and K. Lawless. "Service Territory Baseline and Energy Efficiency Market Potential Study for Nicor Gas Energy Efficiency Program." Bass & Company, 2010.

Table 4-1. Heating Percentage Factor Inputs

Parameter	Description	Units	Source
i	Subscript to specify month (i=1,2,…,12)	–	N/A
j	Subscript to specify year (j=2009,…,2012)	–	N/A
k	Subscript to specify dataset (k=1,2,…,387)	–	Billing data
$HPF_{i,j}$	Heating percentage factor: percentage of gas consumption allocated to heating in month i and year j	%	Calculated
$C_{i,j,k}$	Total heating and non-heating gas consumed in month i, year j, and dataset k	$Therms/month$	Billing data
$(C_{non-heating})_{i,j}$	Average non-heating gas consumption percentage in month i and year j	%	Calculated

Non-heating End Use Calculations

Navigant used the following inputs and calculations to determine billing data disaggregation base loads:

Water Heater Gas Consumption:

$$(C_{Water\ Heater})_i = \left((C_{UA})_i + (C_{Heating})_i\right) * \ n_i * MS_{water\ heater}$$

$$C_{UA} = \frac{(T_{tank} - T_{ambient}) * UA_{tank} * 24\ hrs/day}{\eta_{heating\ element} * 100{,}000\ btu/therm}$$

$$C_{Heating} = \frac{DHW * \frac{Occ_{Nicor}}{Occ_{BA}} * 8.33 * (T_{tank} - T_{mains})}{\eta_{heating\ element} * 100{,}000\ btu/therm}$$

Table 4-2. Water Heater Gas Consumption Algorithm Inputs

Parameter	Description	Units	Source
i	Subscript to specify month (i=1,2,…,12)	$-$	N/A
$(C_{Water\ Heater})_i$	Gas consumption of water heater in month i	$therms/month$	Calculated
$(C_{UA})_i$	Gas consumption due to heat loss through tank walls in month i	$therms/day$	Calculated
$(C_{Heating})_i$	Gas consumption due to heating water from the water mains in month i	$therms/day$	Calculated
n_i	Number of days in month i	$days/month$	N/A
$MS_{water\ heater}$	Market share of gas [versus electric] water heaters (98% of single family homes in the Nicor Gas territory have a gas water heater)	%	Nicor Gas Potential Study
T_{tank}	Temperature set-point of water tank (assumed 125 ˚F)	°F	Illinois TRM
$T_{ambient}$	Temperature of ambient air near water tank (assumed 70 ˚F)	°F	Assumed
$(T_{mains})_i$	Location-specific temperature of water mains in month i	°F	Building America Benchmark
UA_{tank}	Thermal transmittance through the tank walls	$\frac{btu}{hr - °F}$	Building America Benchmark
$\eta_{heating\ element}$	Efficiency of the heating element in the water heater (Assumed 76%)	%	Building America Benchmark
DHW_i	Daily hot water demand in month i	Gal/day	Building America Benchmark
Occ_{Nicor}	Average household occupancy in the Nicor service territory (2.6)	$Persons/household$	Nicor Gas Potential Study (Bass and Company)
Occ_{BA}	Average household occupancy determined by Building America (2.8)	$Persons/household$	Building America Benchmark
8.33	Heat capacity of water	$\frac{btu}{Gal - °F}$	Constant

Clothes Dryer and Stove/Oven Consumption:
Navigant used stove and oven load shapes from Building America.

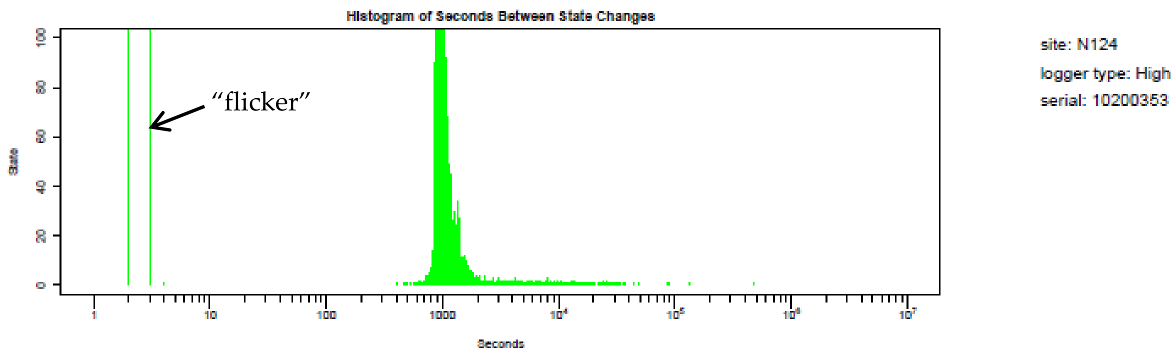
4.2 Logger Data Analysis Methodology

After retrieving the data loggers, Navigant processed the data through two main steps: first, data quality control (QC) and cleaning, and second, transforming the data from a series of on/off events to percent on per hour and hourly gas consumption data for each site.

4.2.1 Data QC and Cleaning

Navigant first analyzed the logger data for quality. We constructed histograms of time between state changes (example in Figure 4-1) to identify "flicker"[18] in each logger file and applied flicker filters to reflect the actual operation of the furnace. Under the condition where the time between state changes is less than the flicker filter limit, the flicker filter corrects the data to the previous state before flicker was observed. The analysis team set a default flicker filter limit at 10 seconds for most loggers.

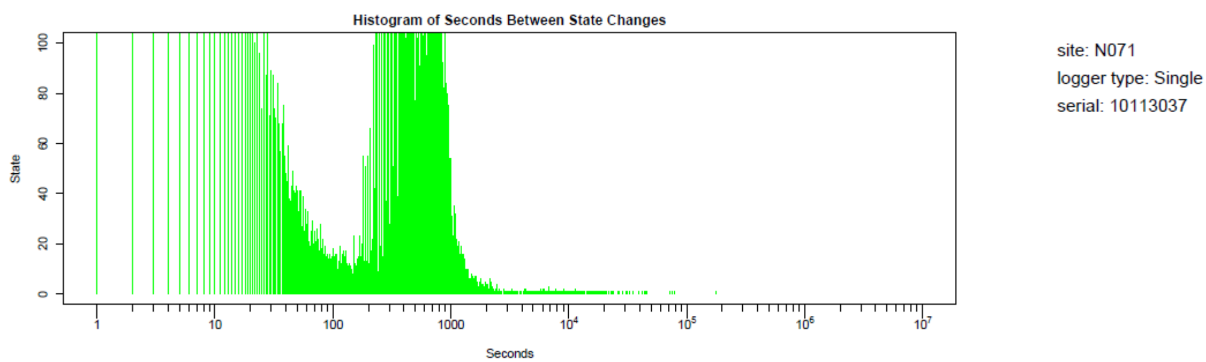
Figure 4-1: Example of Flicker Identification via Histogram Chart of Event Duration



The x-axis is a logarithmic scale of event duration, and the y-axis shows the frequency of event durations. The two spikes and two and three seconds likely indicate flicker (due to nearby currents or startup pulses) and not actual gas consumption.

Navigant set custom flicker filters for loggers that showed significant flicker slightly above 10 seconds. In the example shown in Figure 4-2, Navigant determined that furnace operation is better characterized by setting a flicker filter limit of 20 seconds, which still only reduced the furnace run time estimation by 0.8% compared to no flicker filter limit. Generally flicker filters had a trivial effect (between 0% and 0.8%) on the estimation of furnace run time.

Figure 4-2: Example of High Flicker Identification via Histogram Chart of Event Duration

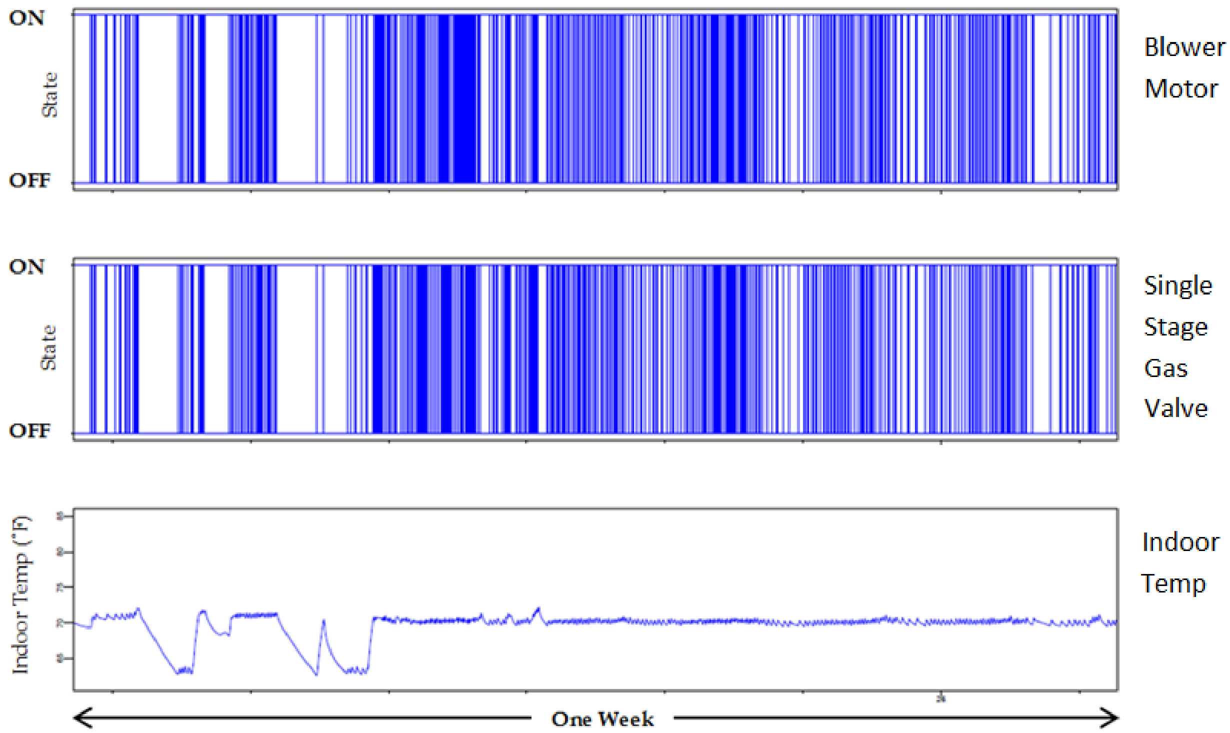


Navigant generated weekly, monthly, and seasonal graphs to ensure the blower motor operation, gas valve operation, and indoor temperature data were consistent. Figure 4-3 shows an example of these weekly graphs, which in this particular case Navigant determined the dataset to be reasonable based on

[18] "Flicker" occurs when the data logger quickly oscillates between the "on" state and "off" state without characterizing the true operation of the furnace.

matching blower (top) and single stage gas valve operation (middle) and the temperature setbacks (bottom) associated with lack of furnace operation.

Figure 4-3: Example Weekly Furnace Operation Graphs



Navigant also used meter readings from the installation and retrieval visits as a quality check to ensure that the calculated furnace consumption estimates did not exceed the home's total metered gas use for the same time period. This step improved the team's ability to identify potential "problem" sites and analysis errors. In the final dataset, several sites showed high (90% or greater) metered consumption relative to the meter readings, but none above 100%. There were also sites on the "low" end; to avoid potential bias, Navigant used data from all 39 homes visited. Although the team experienced some logger failures, the duplicative effort of installing loggers on both the gas valve and blower motor allowed Navigant to estimate gas usage for the one site with a failed gas valve logger (other failures were all on blower motor loggers).

4.2.2 Calculation of Run Time and Gas Consumption

The evaluation team then removed all data on and before the installation date and on and after the retrieval date and converted the filtered logger data into percent "on" per hour for the logging time period. For dual stage furnaces, because the low stage logger was also "on" when the furnace ran in high stage, Navigant subtracted the high stage operation time from the low stage operation time to determine the actual low stage operation time per hour as outlined in the algorithm below:

$$(RunTime_{low})_i = (RunTime_{total})_i - (RunTime_{high})_i$$

Table 4-3. Furnace Run Time Algorithm Inputs

Parameter	Description	Units	Source
$(RunTime_{low})_i$	Low stage furnace run time in hour i	$time$	Calculated
$(RunTime_{total})_i$	Total furnace run time in hour i	$time$	"Low" stage logger data
$(RunTime_{high})_i$	High stage furnace run time in hour i	$time$	"High" stage logger data

Navigant then converted the run time in each stage to actual gas consumption using the gas consumption spot measurements and Nicor Gas' BTU Ratio.[19] The algorithm below outlines the method for calculating the gas consumption of a dual stage furnace.

$$Gas\ Consumption_i = ((RunTime_{low})_i * InputCap_{low} + (RunTime_{high})_i * InputCap_{high}) * BTU\ Ratio$$

Table 4-4. Furnace Gas Consumption Algorithm Inputs

Parameter	Description	Units	Source
$Gas\ Consumption_i$	Furnace gas consumption in hour i	$ft^3\ gas$	Calculated
$(RunTime_{low})_i$	Low stage furnace run time in hour i	$time$	Calculated in algorithm above
$(RunTime_{high})_i$	High stage furnace run time in hour i	$time$	"High" stage logger data
$InputCap_{low}$	Gas input capacity of the low stage	$\frac{BTU}{hour}$	Nameplate or onsite spot measurement
$InputCap_{high}$	Gas input capacity of the high stage	$\frac{BTU}{hour}$	Nameplate or onsite spot measurement
$BTU\ Ratio$	BTU to cubic feet conversion factor	$\frac{ft^3\ gas}{BTU}$	2012-2013 data from Nicor Gas

Navigant summed the gas consumption in each hour to determine the total gas consumption for the duration of the metering period.

[19] The BTU ratio is a conversion factor for converting CCF to BTUs. This ratio varies seasonally and geographically. Navigant used a weighted average BTU ratio of 1.0137 CCF/BTU based on 2012-2013 data from Nicor Gas.