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Empirical Analysis of Natural Gas Furnace Sizing and Operation

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Executive Summary

This report encompasses analysis of minimum natural gas furnaces capacity requirements in the United States, yielding insights on the distribution of furnaces sizes based on region, home attributes (e.g., weatherization), and occupant lifestyle choices such as thermostat setting and use of smart thermostats for energy savings. The report includes: (1) detailed hourly furnace and thermostat operational data for 21 homes obtained during the winter of 2013-2014 in the Chicago metropolitan region and (2) monthly natural gas use and home attributes for over 21,000 homes in various regional markets in Northern Illinois, Minnesota, Eastern Missouri, Arkansas, and Oklahoma. Together, these data were used to empirically determine furnace capacity requirements. These five regions cover four of the DOE/IECC Climate Zones, which encompasses the vast majority of natural gas home heating energy use.

The detailed hourly heating load analysis for Northern Illinois includes 21 randomly selected homes, with dwellings of having varying furnace capacity and efficiency, home size (i.e., real estate square footage), and year of construction. Hourly thermostat, furnace run-time data, and outside temperature data were examined to identify peak space heating loads and furnace capacities during the months of December through February under: (1) **steady-state** thermostat setpoint values and (2) thermostat **setback recovery** operating modes. Analysis of the detailed hourly information yielded equations that were subsequently employed to ascertain the steady-state and setback recovery furnace sizing required for over 21,000 homes in five different climate zones.

Table 1 summarizes the nominal furnace size requirements for the overall dataset as well as the regional breakdown, assuming an 80% furnace efficiency. Taking furnace setback recovery operation as a valuable and preferred consumer option that saves energy, furnaces in the size range of 68,000 Btu/hour (median, 50th percentile) to 84,600 Btu/hour (80th percentile) should satisfactorily meet the needs of most natural gas customers; steady-state operational data with an appropriate DOE/ACCA sizing factor of 1.35 are consistent with these findings.

Table 1: Summary Furnace Capacity Requirements (80% efficient furnace)

All Five Regions	**Steady-State Operation (Btu/hour) With 1.35 DOE/ACCA Sizing Factor**	**Setback Recovery Operation (Btu/hour)**
80th Percentile Capacity	83,070	84,627
Average Capacity	67,607	70,538
Median Capacity	65,147	68,031
Regional Findings	80th Percentile Steady-State Operation (Btu/hour)	80th Percentile Setback Recovery Operation (Btu/hour)
Minnesota	61,931	65,376
Missouri	80,055	81,860
Illinois	83,353	84,859
Oklahoma	97,035	97,303
Arkansas	100,717	100,652

Perhaps counterintuitively, the furnace sizing requirements increased for homes located in DOE/IECC Climate Zone 3 which encompasses Southern, cooling-dominated regions (e.g., around Little Rock, Arkansas and Oklahoma City, Oklahoma). The data give clear findings that these homes exhibit distinctly lower levels of weatherization that translate into higher rates of building heat loss during the peak heating months of December through February. These home weatherization attributes necessitate higher than anticipated peak furnace capacity ratings in the two specific Climate Zone 3 Southern regions included in this analysis.

Background

According to the U.S. Bureau of Census (2014 data), there are approximately 57 million homes using natural gas to meet their space heating requirements. An estimated 52.6% of owner-occupied homes across the U.S. use natural gas for home heating. Furnaces represent about 80% of the market, the balance being steam and hot water systems. Nearly 3 Quads of natural gas is used for home heating.

Sizing natural gas furnaces to meet the space heating needs of homes can be done using procedures, for example, in Manual J published by the Air Conditioning Contractors of America and ASHRAE technical publications. These provide a detailed analytical framework for estimating the surfaces of the building envelope, insulation level, window and door attributes, house infiltration rates, and other factors.

In practice, houses have widely varying construction attributes as well as a range of choices made by homeowners in terms of how they live. For example, homes may have differences in the performance of windows or insulation based their quality, how they were installed, or due to deterioration. These differences can be systematic – for example, differences in regional building practices – or specific to the behavioral attributes and lifestyle choices people make. For example, homeowners have widely varying views regarding preferred thermostat setpoints for indoor comfort (Figure 1).

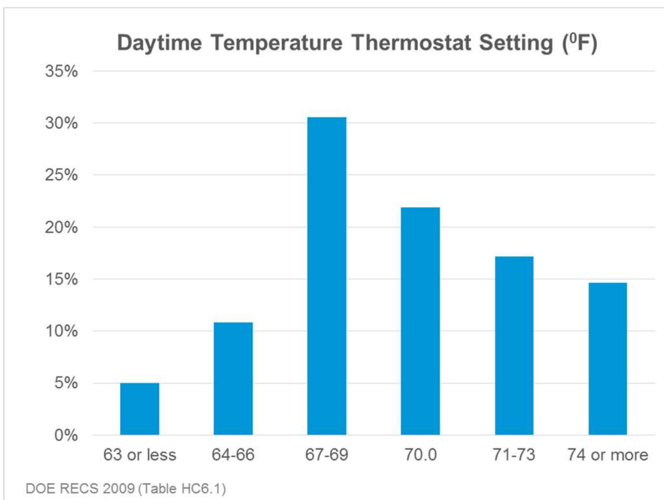


Figure 1: Distribution of Homeowner Choices on Space Heating Thermostat Setting

Minimum furnace size requirements to meet occupant needs and preferences becomes even more complicated when considering the increasing market impact of programmable or smart thermostats. These devices provide homeowners with energy saving features such as multiple thermostat setback options during overnight periods or during the day when the home is not occupied. Smart thermostats go even further by providing highly dynamic, learned thermostat setpoint operation based on occupant preferences and weather patterns. To examine the impacts of these complexities on furnace sizing recommendations and guidelines, empirical data is needed to supplement design guidelines such as ACCA Manual J that employ simplified assumptions about home characteristics and occupant behavior. Empirical data can provide insights into actual home heating needs based on the true physical condition of homes, the lifestyle choices that energy consumers make, and the role of new technology such as smart thermostats. This empirical data can help to calibrate computer models used in guidelines such as ACCA Manual J to ensure that furnace capacities meet a wide range of consumer needs and building types and condition.

Project Introduction

The objective of this project was to analyze empirical, real-world information on the sizing and operation of natural gas furnaces in homes across the US. This initially looked at detailed furnace and thermostat operation for homes in the Chicago metro area. These data provide insights on home weatherization as well as furnace and thermostat operation that enabled the derivation of furnace sizing equations based upon real-world homes and consumer behavior.

From this, GTI analysts extended the study to a larger set of homes (about 18,000) in the Chicago area using monthly natural gas consumption for one year. Methodologies were derived to ascertain (1) the approximate home monthly space heating loads during the peak heating months of December through February and (2) building UA Value – a measure which incorporates home weatherization attributes (defined in a subsequent section of this report). This approach was then applied to homes in Minnesota, Missouri, Arkansas, and Oklahoma to provide a better understanding of regional building characteristics. In total, this analysis of gas company billing databases analyzed the space heating requirements for over 21,000 homes in five DOE/IECC climate zones.

As part of a Nicor Energy emerging technology program measurement and verification project, GTI previously collected information to quantify smart thermostat energy (heating and cooling) savings on Chicago metro area homes during a twelve month period in 2013-2014. This included 54 thermostats in 49 homes – both single-family and multi-family dwellings. For each site, 8,760 hourly datapoints were gathered (excluding instances of data unavailability).

For this furnace sizing analysis, a subset of 42 homes were identified as single-family dwellings with a single furnace. From this, GTI randomly selected 21 homes for detailed analysis. This group of 21 homes fairly represents the larger group of homes, including dwellings with varying levels of efficiency (as measured by UA Value), size (i.e., square footage), and year of construction.

As shown in Figure 2, Chicago falls in the DOE/IECC Climate Zone 5. This represents a significant portion of the country's population – particularly in the Midwest and Northeast. Less densely populated Zone 6 and Zone 7 have greater heating degree days (HDD). Notably, the detailed furnace and thermostat operational data were obtained during the winter of 2013-2014 in Chicago – a particularly harsh winter – which is helpful in terms of understanding empirical furnace sizing requirements.

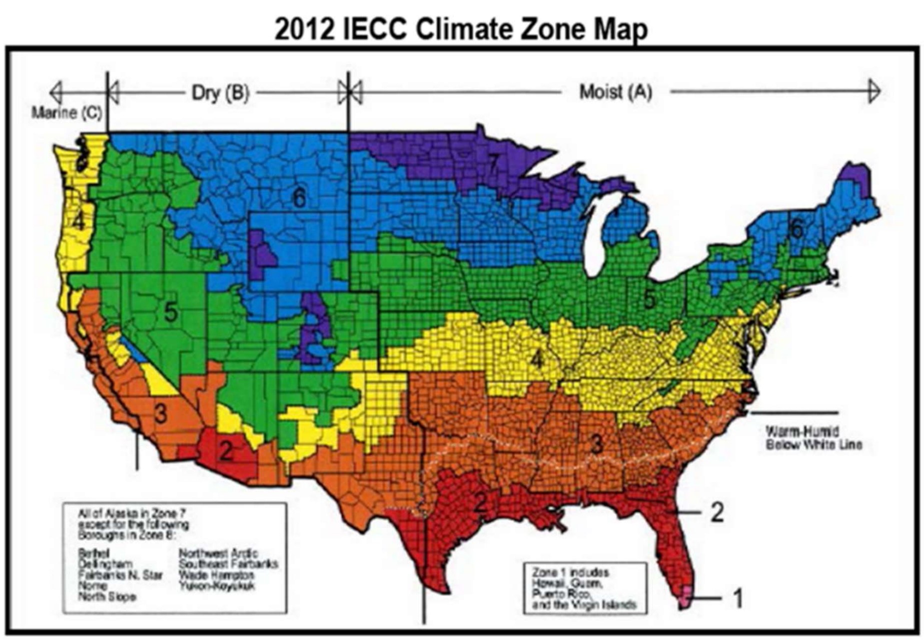


Figure 2: DOE/IECC Climate Zone Map

The Chicago metropolitan region lies in the upper portion of DOE/IECC Climate Zone 5 – and below more extreme regions in Climate Zones 6 and 7. The following table provides ASHRAE information on extreme heating design temperature (99^{th} percentile) and heating degree days (HDD, 65ºF base) for a select number of cities. This includes areas encompassed in this analysis – Chicago, Minneapolis, St. Louis, Little Rock, and Oklahoma City – as well as other more extreme northern tier locations.

Nationally, Chicago is representative of a heating-dominated region, with a 99 percentile design temperature of 3.7ºF and 6,209 HDD. There are many locations in Zones 6 and 7 with more extreme space heating requirements. For example, Minneapolis has an annual HDD value of 7,472 (20% more than Chicago) and Fargo, ND has a HDD value of 8,729 (40% greater than Chicago). The 99^{th} percentile design temperatures for Minneapolis and Fargo are, respectively, minus 6.2ºF and minus 14.5ºF (differential of 9.9 and 18.2 degrees from Chicago). Using the equation for UA Value (described in a following section), the same home in Chicago would nominally require a furnace with 3.6% larger capacity in Minneapolis and 15.7% larger in Fargo.

Empirical, real-world data is needed to ascertain specific furnace sizing requirements for homes located in different climate zones. As illustrated in this report, actual furnace and thermostat operation – and home construction attributes – result in highly variable and, in some instances, counterintuitive results. This necessitates an empirical, rather than a purely analytical, approach to understanding real-word residential space heating requirements.

Table 2: ASHRAE Handbook (2013) Heating Design Values

City	ASHRAE 99% Heating Design Temperature (ºF, dry bulb)	ASHRAE Heating Degree Days (65ºF base)	Heating Degree Days (for year analyzed in this report)
Chicago, IL	3.7	6,209	7,548 (2013/14) 6,657 (2010/11)
Minneapolis, MN	-6.2	7,472	6,283 (2015/16)
St. Louis, MO	11.7	4,436	4,552 (2008/09)
Oklahoma City, OK	18.2	3,487	1,944 (2015/16)
Little Rock, AR	23.3	3,158	1,453 (2015/16)
Buffalo, NY	7.4	6,508	N/A
Milwaukee, WI	3.2	6,684	N/A
Billings, MT	-3.2	6,705	N/A
Sioux Falls, SD	-7.3	7,470	N/A
Fargo, ND	-14.5	8,729	N/A

Methodology and Data Analysis

The data analysis includes two primary sections:

- Detailed hourly analysis of furnace and thermostat operation to derive furnace sizing equations based upon empirically calculated home UA Value (see below).
- Application of furnace sizing equations to over 21,000 homes in five different DOE/IECC climate zones. This uses monthly natural gas consumption, methodologies to ascertain space heating load, meteorological data (i.e., heating degree day) to derive to home UA Value and thereby determine furnace sizing.

UA Value is used extensively throughout this report and is shown to be the most appropriate metric for determining home space heating requirements in a given region. UA Value can be empirically (and conveniently) found using the following equation:

$$UA\ (Btu/hr\text{-}F) = Q\ (Btu/hr)/[T_{indoor}\ (F) - T_{outdoor}\ (F)]$$

Q is the energy input into the home – for example the delivered energy from a gas furnace net of flue gas losses and T represents the temperature difference between the interior of the home (e.g., thermostat setting) and the outside environment. Importantly, these quantities can be readily measured.

The terminology "UA" is used in engineering heat transfer analysis to capture: (1) U, the overall heat transfer coefficient (in Btu/hr-F-ft^2) of the building multiplied by (2) A, the building's surface area (in ft^2). This square footage is not the floor area, but is the heat exchange surface area (i.e., walls, roof, etc.) defined at the thermal envelope boundaries – that is, where the insulation begins/ends. The magnitude of U for a given home can be lowered through weatherization techniques such adding insulation, using energy efficient windows, air sealing, etc. The value of A can be influenced by building design – for example by reducing the exposed area for energy loss (especially through the roof). In practice, knowing the individual numeric value of U or A is difficult, but the above equation permits an empirical approach to understanding U*A for a given building using readily measured values of furnace energy use, efficiency, and temperature readings inside and outside the home.

Detailed Hourly Chicago Area Home, Furnace, and Gas Use Attributes

The dataset from the smart thermostat program included hourly data on 42 homes with a single furnace. Table 3 summarizes key attributes of the homes and furnaces. The homes have a random distribution of year built, square footage, furnace size, and UA Values (described in a subsequent section). From these 42 homes, a subset of 21 homes were randomly selected for more detailed data analysis, while ensuring a fair distribution of UA Values.

Table 3: Home and Furnace Characteristics

City in Illinois	Furnace Size Btu/hr input	Efficiency AFUE, %	UA Value	Heating Degree Days	Space Heating Gas Use (Therms/yr)	Year Built	Square Footage
Arlington Heights	122,222	90	517	7,406	1,103	1977	3,002
Arlington Heights	77,778	90	449	7,406	1,062	1948	1,728
Aurora	86,957	92	215	7,728	508		
Barrington	125,000	80	643	7,329	1,508	1988	1,615
Bartlett	125,000	80	408	7,546	1,001	1995	2,040
Belvidere	90,000	80	371	7,848	995	1930	1,132

Buffalo Grove	125,000	80	616	7,213	1,675	1978	2,018
Buffalo Grove	187,500	80	1,104	7,394	2,718		
Carpentersville	187,500	80	1,127	7,750	2,879	2001	3,264
Cherry Valley	112,500	80	741	7,872	2,123		
Diamond	100,000	90	336	7,200	745	2003	2,320
Geneva	168,750	80	959	7,703	2,274		
Geneva	168,750	80	603	7,746	1,343		
Glenview	168,750	80	765	7,400	1,696		
Hillside	87,500	80	521	7,311	1,275	1958	1,073
Homer Township	125,000	80	432	7,501	1,092	1988	1,288
McHenry	137,500	80	528	8,065	1,464	1981	1,950
Montgomery	86,957	92	426	7,644	920		
Montgomery	125,000	80	567	7,822	1,560	2002	2,750
Montgomery	165,000	80	667	7,684	1,647		
Mount Prospect	157,143	70	420	7,405	1,072		
Naperville	87,500	80	424	7,749	1,160		
Naperville	125,000	80	706	7,749	1,632	1987	2,012
Oak Park	187,500	80	908	7,036	2,383		
Plainfield	125,000	80	301	7,307	786	1996	1,510
Romeoville	137,500	80	662	7,528	1,865	2002	2,254
Romeoville	93,750	80	290	7,538	853		
Romeoville	100,000	80	475	7,487	1,286	2000	1,427
Round Lake	87,500	80	217	7,549	522		
Round Lake	137,500	80	784	8,002	1,895	2002	3,006
Schaumburg	93,750	80	677	7,319	1,596		
Skokie	112,500	80	419	7,255	1,122		
South Holland	125,000	80	966	7,712	2,347	1967	1,461
Streamwood	142,857	70	387	7,690	1,219		
Sugar Grove	97,826	92	597	7,818	1,384	2004	2,818
Volo	87,500	80	268	7,879	729	2004	1,656
Wheaton	100,000	80	440	7,751	1,013		
Wheaton	112,500	80	350	7,689	856	1977	1,377
Wheaton	171,429	70	699	7,288	1,832		
Woodridge	150,000	80	469	7,185	1,178		
Woodstock	137,500	80	393	8,870	1,073		
Worth	125,000	80	651	6,818	1,673		

Table 4 provides summary statistics of the homes and furnaces included in the detailed hourly study.

Table 4: Summary Statistics on Homes and Furnaces

	Home Square Footage	Furnace Rating (Btu/hr)	UA Value	Therm Use
Average	2,036	125,403	560	1,406
Standard Deviation	671	31,179	224	557
Minimum	1,073	77,778	215	508
Maximum	3,264	187,500	1,127	2,879

Using furnace gas consumption data, efficiency rating, and available indoor and outdoor temperatures, GTI analysts calculated an empirical UA Value for each home. Daily UA Values were derived, summed, and averaged to provide an overall UA Value for each home during an entire year. Figure 3 shows the strong correlation between a home's UA Value and space heating energy use (R^2=0.96).

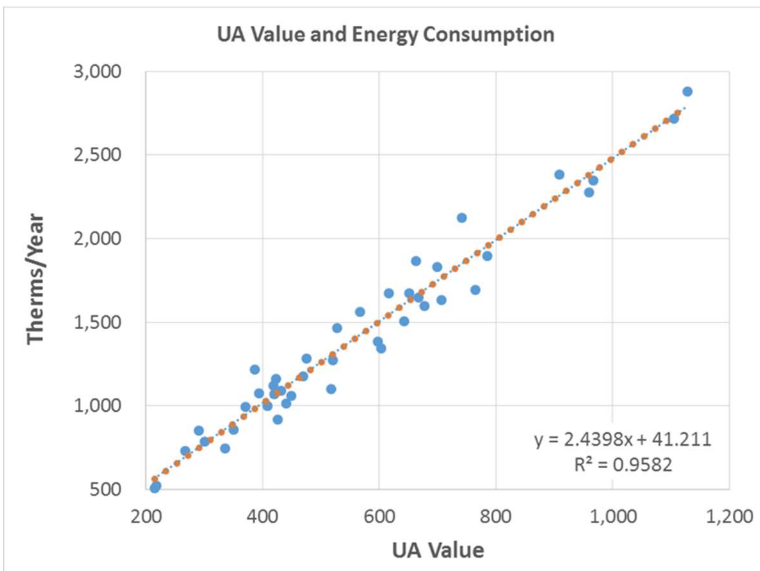


Figure 3: Relationship Between UA Value and Furnace Natural Gas Use

Figure 4 shows the highly variable relationship between home size (i.e., square footage) and energy use. There is a positive, but weak, correlation between these factors (R^2=0.26). This poor correlation corroborates that even homes of equal size in a given region can have dramatically different heating requirements based upon (1) the as-built building "tightness" and efficiency and (2) homeowner behavior such as thermostat setting and setback strategies.

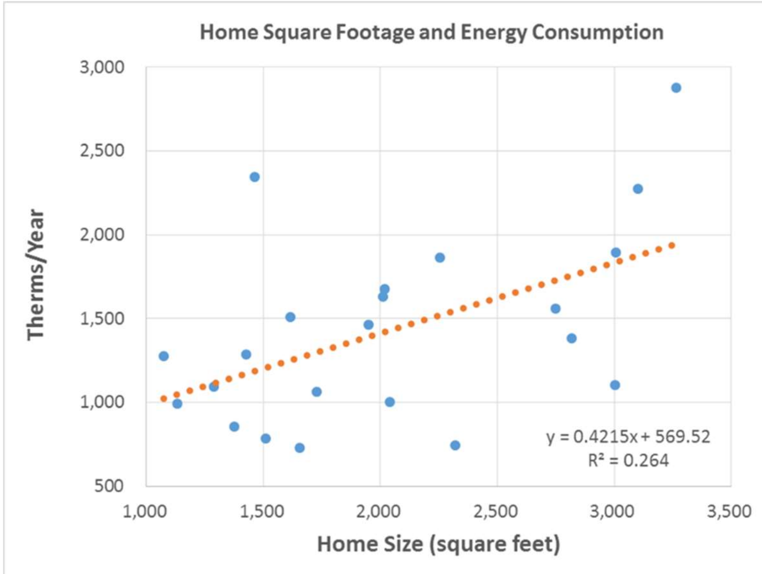


Figure 4: Home Size (ft^2) and Energy Use

Figure 5 highlights the poor correlation between home UA Value and the home's square footage of living area. Homes of equal size can have widely varying UA Value and energy consumption attributes, including peak load and furnace capacity needs.

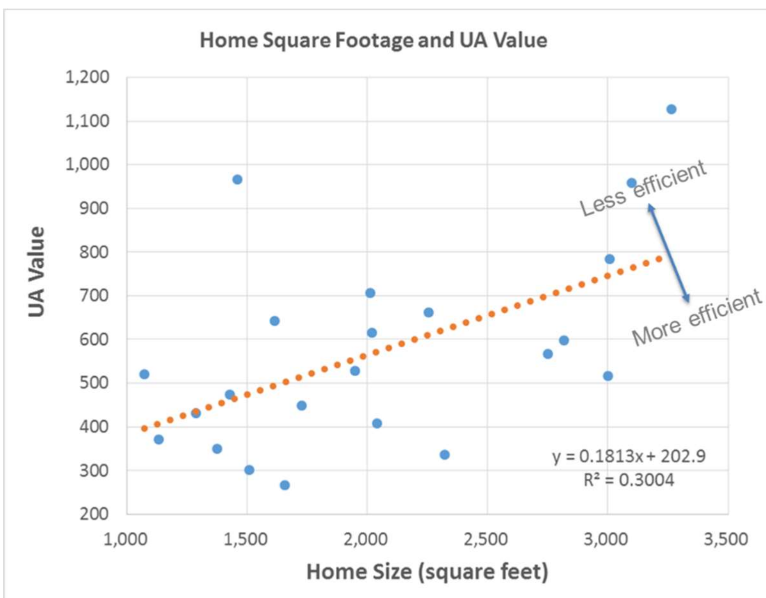


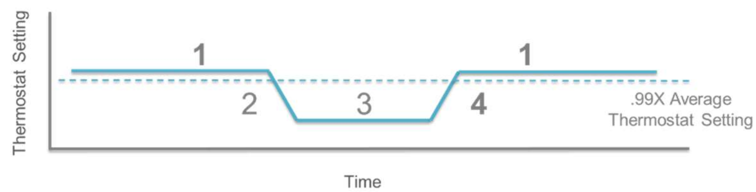
Figure 5: Home Size and UA Value

Detailed Hourly Chicago Area Thermostat and Furnace Operation Analysis

GTI analysts conducted an analysis of hourly thermostat setpoint and furnace operation during the months of December 1, 2013 through March 19, 2014. This included a total of 2,616 hours (part of a complete

8,760 year-round monitoring of furnace and air conditioning operation) for 21 homes in the Chicago metro area.

Figure 6 illustrates prototypical programmable or smart thermostat operating states with setback operation. For this furnace sizing analysis, hourly thermostat and furnace run-time data were examined to identify two key operating modes: (1) **steady-state** thermostat setpoint values and (2) thermostat **setback recovery**. These two furnace operating states can be used to characterize nominal furnace energy input capacity requirements for home heating. Mathematical algorithms based on actual temperature at the thermostat were employed to determine these operating states.



Thermostat State	Description
1	**Steady State Operation**
2	Setback Ramp Down
3	Setback Dwell
4	**Setback Recovery**

Figure 6: Thermostat Operating States

Data from two other thermostat states – that is, during thermostat setback periods of ramp down and dwell at temperatures below average setpoint values – were not analyzed since they represent atypical operating points from a furnace capacity sizing perspective. By analogy, setback ramp down and dwell are similar to a vehicle going downhill or an engine idling; these would not be particularly relevant to an automotive design engineer looking to size the power requirements of an engine.

Determination of Steady State Setpoint and Setback Recovery Operation

Within the database, an hourly "heating slope" value was calculated by taking the difference in thermostat setting for the previous and subsequent hour (a three-hour span). Slopes in close proximity to zero represent steady-state operation; a negative value directionally indicates thermostat ramp down, while a positive value directionally indicates thermostat recovery (ramp up).

Steady-state operation was defined as a timeframe where, over a three hour period, the thermostat setting changed very little and was in close proximity to the average thermostat setting for the home. The logic for this was defined as being above 0.995 of the average thermostat setting and a heating slope of less than 0.3^{o}F. To eliminate potential transition periods between thermostat operating states, hourly furnace run times of less than six minutes were excluded.

Setback recovery was defined as having a heating slope value greater than 2^{o}F per hour. Similarly, to eliminate potential transition periods between thermostat operating states, hourly furnace run times of less than six minutes were excluded.

Table 5 shows summary statistics from detailed analysis of 21 homes. The manner in which homeowners employed smart thermostats varied in terms of frequency of setpoint changes and the amplitude of changes (e.g., setback temperature). Some homeowners used a thermostat setback as large as 7 to 10^{o}F, while others more commonly used values ranging from 2-4 ºF. In all cases, steady state operating hours exceeded setback recovery hours.

Table 5: Summary of Thermostat Steady-State and Setback Recovery Operating Hours

Number of Hours	Steady-State Operation	Setback Recovery Operation
Average	780	169
Standard Deviation	311	110
Minimum	398	11
Maximum	1,665	362

Figure 7, Figure 8, and Figure 9 illustrate the highly variable nature by which homeowners operate smart thermostats. There were significant differences in the frequency and amplitude in thermostat settings. The mathematical algorithms provided a consistent manner for screening these data to determine steady-state operation and setback recovery periods.

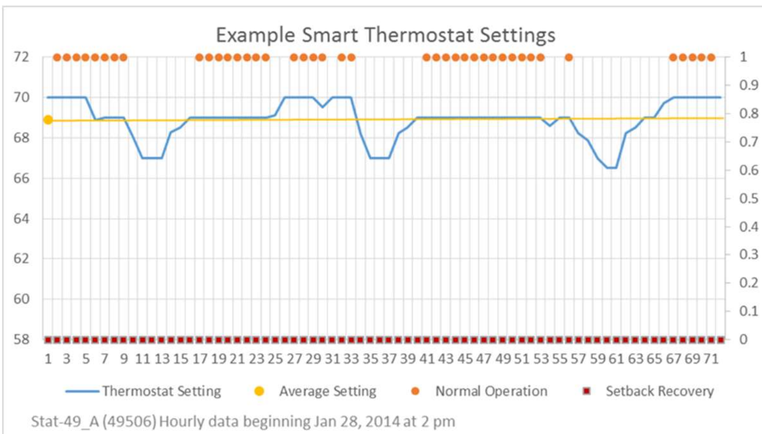


Figure 7: Thermostat Operation With Low Frequency and Amplitude

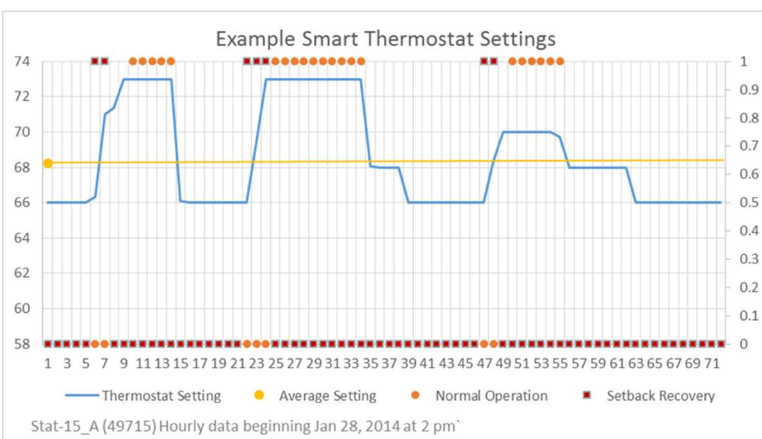


Figure 8: Thermostat Operation With Moderate Frequency and Amplitude

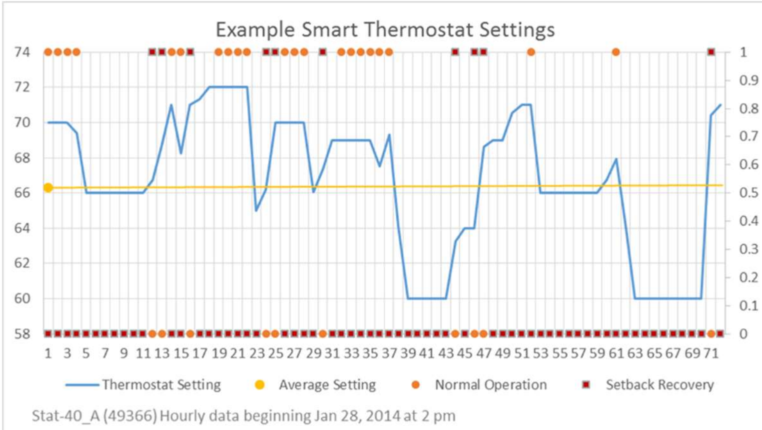


Figure 9: Thermostat Operation With High Frequency and Amplitude

Furnace Capacity Requirements During Steady-State and Setback Recovery Operation

Using the previously described algorithms to identify steady-state and setback recovery operating states, a more detailed analysis of the 21 sites was undertaken. For each hour, data were available on furnace run time as well as indoor and outdoor temperature. Using the run time information and furnace input rating, a calculation was made of the estimated hourly Btu energy input into the furnace.

Figure 10 illustrates hourly run time information for one home as a function of outdoor temperature and furnace operating state (steady-state and setback recovery modes). This example home has a 125,000 Btu/hour furnace and a relatively efficient UA Value of 432. There is significant data scatter, but trend lines show anticipated increases in run time with colder temperatures. Further, run times are generally higher during setback recovery periods. An appendix to this report contains scatter plots for all 21 homes.

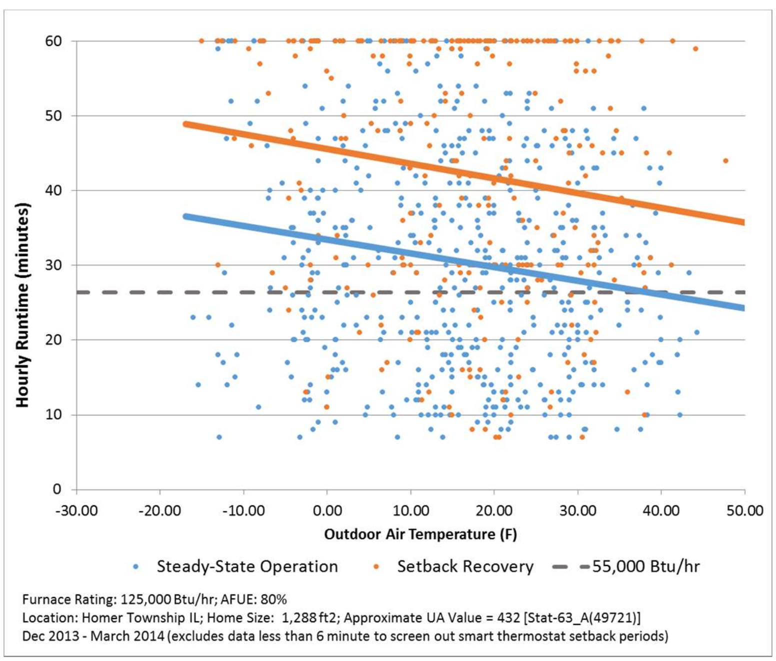


Figure 10: Example Furnace Steady-State and Setback Recovery Operation

From these data, a furnace rating requirement was derived for steady-state operation and setback recovery. The capacity requirement was defined as the 80th percentile value of data for each operating state. Table 3 shows this value for the data illustrated in Figure 10. To interpret these figures, 80% of the steady-state operating hours required a furnace rated at 93,750 Btu/hour or less (75% of the furnace's actual 125,000 Btu/hour rating). During setback recovery, the 80th percentile figure was equal to the furnace capacity, meaning that at least 80% of the setback recovery operational hours used the full 125,000 Btu/hr furnace capacity. This highlights the typically extended furnace operation, and higher input firing rate, necessary to raise the home's temperature from a thermostat setback point.

Table 6: Homer Township (Thermostat 63) Furnace Capacity Requirement

	Steady State Operation	Setback Recovery
80th Percentile Value	93,750	125,000
Count	535	270

Table 7 summarizes the steady-state and setback recovery capacities for the 21 homes analyzed. The average steady-state operating furnace capacity was about 77,500 Btu/hour (77,527 Btu/hour) and about 108,000 Btu/hour (107,859 Btu/hour) for setback recovery operation. The average setback recovery capacity was about 30,000 Btu/hour greater than required for steady-state operating periods. As discussed, home attributes (specifically, UA Value) and homeowner lifestyle choices result in highly variable outcomes. For example, the magnitude of thermostat setback varies; some homeowners employ temperature setback ranging from 7-10ºF, while others would typically be in the range of 2-4 ºF of thermostat setback.

Table 7: Summary of Furnace Steady-State and Setback Recovery Capacity Requirements

City in Illinois	Furnace Rating Btu/hr input	UA Value	Gas Use (Therms/year)	Steady-State Operating Capacity (80th percentile)	Setback Recovery Capacity (80th percentile)
Average	**125,403**	**560**	**1,406**	**79,244**	**110,627**
Plainfield	125,000	301	786	39,583	68,750
Arlington Heights	77,778	449	1,062	45,371	77,778
Belvidere	90,000	371	995	49,500	61,500
Romeoville	100,000	475	1,286	51,667	65,667
Volo	87,500	268	729	52,500	86,042
Wheaton	112,500	350	856	56,250	112,500
Diamond	100,000	336	745	56,667	98,333
Hillside	87,500	521	1,275	56,875	87,500
Bartlett	125,000	408	1,001	65,000	125,000
Barrington	125,000	643	1,508	68,750	93,750
McHenry	137,500	528	1,464	68,750	119,625
Buffalo Grove	125,000	616	1,675	72,917	125,000
Montgomery	125,000	567	1,560	72,917	125,000
Romeoville	137,500	662	1,865	75,625	98,542

Sugar Grove	97,826	597	1,384	89,674	97,826
Homer Township	125,000	432	1,092	93,750	125,000
Arlington Heights	122,222	517	1,103	101,852	122,222
Naperville	125,000	706	1,632	116,667	125,000
South Holland	125,000	966	2,347	125,000	125,000
Carpentersville	187,500	1,127	2,879	131,250	187,500
Round Lake	137,500	784	1,895	137,500	137,500

Figure 11 provides an illustration of a "load duration curve" distribution for steady-state furnace input firing rates (535 hours) for the Homer Township home shown in Figure 10 as well as operation during setback recovery (270 hours). Of the hours firing at steady-state conditions, 80% of them were at 93,750 Btu/hour or less; conversely, 20% were above this firing rate. For comparison, a 55,000 Btu/hour furnace would be sufficient for about 42% of the steady-state operating hours. For purposes of operation during setback recovery, this home spent 89% of the setback recovery time above 55,000 Btu/hour. Even for this relatively efficient home, with UA Value of 432, substantial time (161 hours) was spent at firing rates well above 55,000 Btu/hour of heat input.

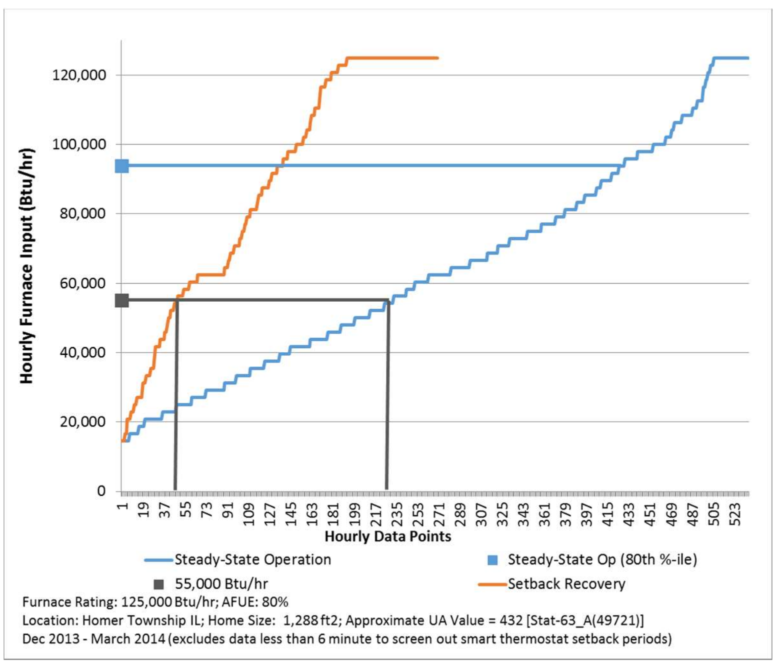


Figure 11: Steady-State Operating Mode Hourly Furnace Input Rate Distribution (Homer Township)

Figure 12 shows a similar "load duration curve" for a more efficient home (UA Value 350). In this example, a 55,000 Btu/hour furnace could meet about 75% of the steady-state furnace input firing rate need, but as shown there remain significant peak heating hours requiring larger hourly heat input. A smaller furnace could only meet 25-30% of the setback recovery hourly needs. About 275 hours were at firing rates above 55,000 Btu/hour, a sizeable portion of which were nearly double this firing rate.

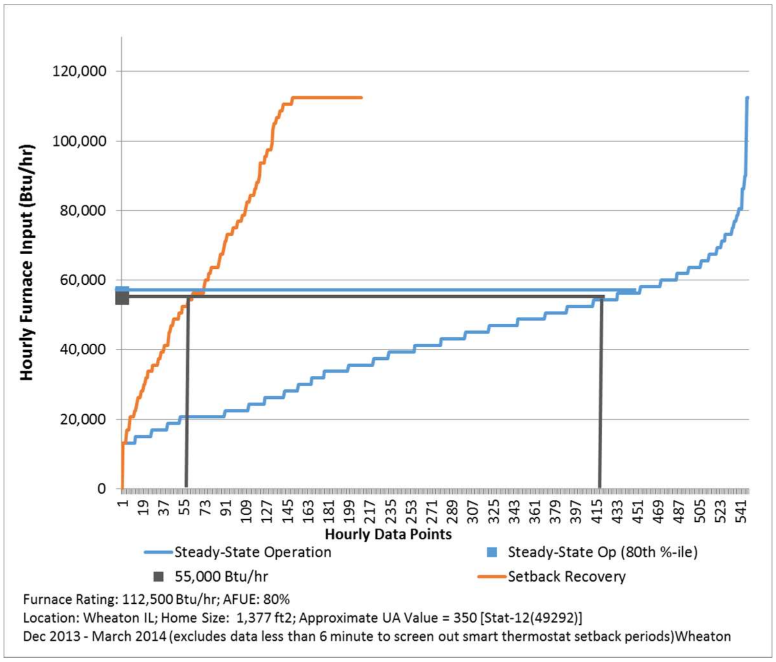


Figure 12: Steady State Operating Mode Hourly Furnace Input Rate Distribution (Wheaton)

Figure 13 shows a similar "load duration curve" for a home (UA Value 567) that is representative of an average home in this analysis. In this particular home, a 55,000 Btu/hour furnace would meet about 53% of the steady-state furnace input firing rate need, leaving significant number of peak heating hours requiring larger hourly heat input. A 55,000 Btu/hour furnace could only meet 29% of the setback recovery hourly needs. About 590 hours were at firing rates above 55,000 Btu/hour, a meaningful portion of which are at 50% to 100% higher firing rates.

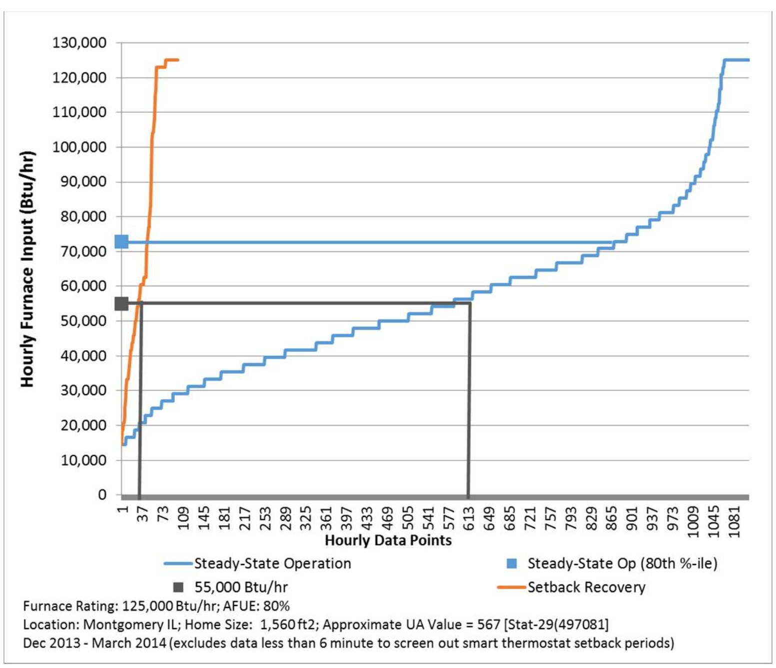


Figure 13: Steady-State Operating Mode Hourly Furnace Input Rate Distribution (Montgomery)

Based on this analysis, an average home – and even more efficient homes – furnace ratings well in excess of 55,000 Btu/hour are needed for a significant portion of the peak heating months of December through February. Even smaller and more efficient homes would likely see meaningful loss in heating function if required to install a 55,000 Btu/hour furnace.

Figure 14 shows the main results from this analysis, with the following three key points:

1. A small minority of homes (UA Values of 400 and less) from this analysis may be able to see most, but not all, their steady state space heating needs met by a 55,000 Btu/hour furnace. However, even these relatively efficient homes would see extended hours where a 55,000 Btu/hour furnace would likely be undersized and could compromise homeowner comfort.
2. In the vast majority of homes (UA Values over 400), a 55,000 Btu/hour furnace is increasingly insufficient in meeting their peak heating demand requirements as UA Value increases above 400.
3. In all cases, a 55,000 Btu/hour furnace would likely compromise setback recovery performance. Homeowners would be likely be inclined to limit the extent, or stop employing, thermostat setback as an energy efficiency measure.

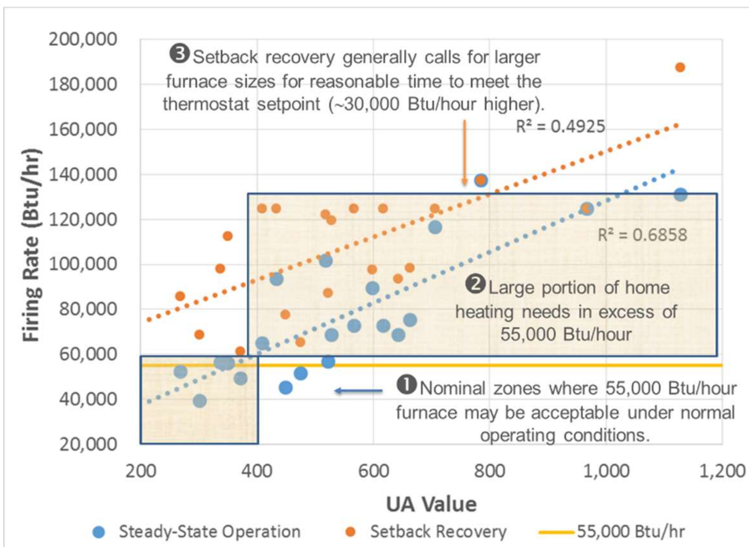


Figure 14: UA Value (Dec-Feb) and Furnace Capacity Requirements

As shown in Figure 15, all homes exhibited periods that called for more than 55,000 Btu/hour during peak heating periods (January-February). Even smaller and "tighter" homes (UA Value below 400) had 10-30% of on-time hours employing more than 55,000 Btu/hour. The vast majority of homes over UA Value 400 spent 40-90% of on-time at firing rates above 55,000 Btu/hour.

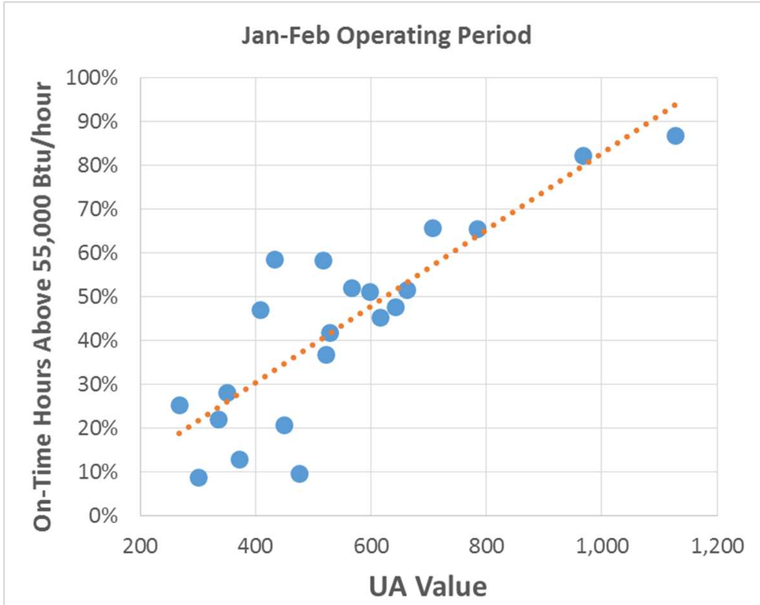


Figure 15: Peak Heating Operating Hours Above 55,000 Btu/hour

For these 21 homes, GTI analysts derived equations that relate UA Value to peak heating period capacity for (1) steady-state capacity and (2) for thermostat setback recovery operation. Figure 16 shows the data used to derive these equations. From the 21 homes, GTI analysts selectively removed outlier data to lower scatter and maximize the R^2 value (0.8251 and 0.8056, respectively); these changes uniformly acted to reduce calculated furnace capacity compared to the full dataset. Note that the net energy delivery rate in this figure and the equations would need to be divided by efficiency to obtain gross furnace input capacity. The DOE/ACCA furnace sizing factor of 1.35 was applied to the steady-state energy delivery rate to accommodate for a range of uncertainty in furnace sizing, consistent with ACCA Manual S and DOE analysis.

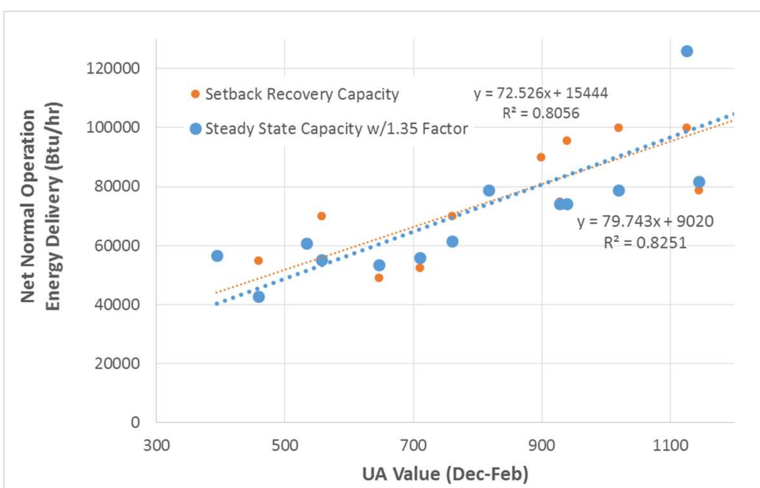


Figure 16: UA Value (Dec-Feb) and Delivered Energy Rate for Steady-State and Setback Recovery

To facilitate determining peak heating requirements from a larger dataset of natural gas use in homes, we calculated UA Values for the peak months of December through February. For this population of homes, this UA Value (Dec-Feb) averaged 12% higher than the UA Value calculated over the entire year. The two equations are:

Net Steady-State Energy Deliver Rate (Btu/hr) = [79.743 * UA Value (Dec-Feb)] + 9,020

Net Setback Recovery Energy Delivery Rate (Btu/hr) = [72.526 * UA Value (Dec-Feb)] + 15,444

Space Heating Analysis of a Larger Population of U.S. Homes

GTI conducted an analysis of a much larger population of homes using monthly natural gas energy use data supplied by various natural gas utilities across the U.S. This encompassed homes in Northern Illinois (Chicago metro area), Minnesota (Minneapolis/St. Paul metro area, Eastern Missouri (St. Louis metro area), Arkansas (Little Rock and surrounding areas), and Oklahoma (Oklahoma City and surrounding areas). Where possible, this data was supplemented with information about the home – for example, year of construction and square footage – along with meteorological data such as outdoor temperature and heating degree day.

The largest of these datasets was in the Chicago metro area, encompassing monthly natural gas use and furnace efficiency for over 18,000 homes. These data were coupled with local monthly heating degree day data to determine home UA Values during the December through February period (as described below). GTI then extended this methodology for determining UA Value to other homes in Minnesota, Missouri, Arkansas, and Oklahoma. Using the relationships described previously linking UA Value to steady-state and setback recovery furnace operation, GTI analysts calculated the estimated furnace capacity for all these homes.

As described earlier, UA Value is defined as:

$$UA\ (Btu/hr\text{-}F) = Q\ (Btu/hr)/[T_{indoor}\ (F) - T_{outdoor}\ (F)]$$

From this larger data set of monthly natural gas use, GTI used the following steps to estimate home UA Value during the December through February peak heating season.

1. Summed up December, January, and February total gas use.
2. Found the average summer monthly natural gas use (during June-August). This represents the nominal monthly gas use for non-space heating loads (e.g., mainly water heating along with cooking and drying).
3. Subtracted 3.X times (i.e., three months) the value from Step 2 from the results of Step 1, multiplied by furnace efficiency, and divided this number the total number of hours in December, January, and February. This value is Q in the above equation – average net Btu/hr of delivered energy from the furnace. GTI applied a factor of 3 times the average summer months use plus an amount (.X) to account for greater heating energy required to raise water temperature in the winter as compared to the summer (i.e., due to lower below ground temperatures in the winter). For Minnesota, GTI analysts used 3.35, Illinois and Missouri a factor of 3.3, and Arkansas and Oklahoma a factor of 3.25.
4. The heating degree days for December, January, and February were summed and divided by the number of days in those three months to get the average indoor – outdoor temperature difference.
5. Divided Step 3 by Step 4 to derive the UA Value for December through February.
6. The analysis focused on homes with a UA Value of 250 to 1100. The numbers below 250 likely represent multi-family residences, while values above 1100 are more likely large homes (which may in some instances use more than one furnace).
7. The prior equations linking furnace capacity to home UA Value were used to ascertain the steady-state furnace size (with the DOE/ACCA sizing factor) and the setback recovery capacity.

Illinois (Chicago Area) Homes

Figure 17 shows the results of the UA Values (Dec-Jan) calculation for this larger population of nearly 18,000 Northern Illinois area homes (using December 2010 – February 2011 data). Note that the data in this figure excludes homes below UA Value 250 and above 1100 (less than 10% of all the homes in this dataset). Table 8 provides summary statistics on this population of 17,978 Chicago metro area homes. Using the relationship between UA Value (Dec-Feb) and net delivered energy required, GTI analysts calculated steady state with the DOE/ACCA 1.35 sizing factor and setback recovery furnace capacity requirements for 80% efficient furnaces.

Table 8: Characteristics for Illinois Homes (Chicago Area)

	UA Value (Dec-Feb)	Steady State Furnace Capacity With 1.35 DOE/ACCA Sizing Factor (Btu/hr, 80% efficiency)	Setback Recovery Furnace Capacity (Btu/hr, 80% efficiency)
80th Percentile	723	83,353	84,859
Average	568	67,871	70,779
Median	543	65,447	68,574
Standard Deviation	185	17,978	17,978

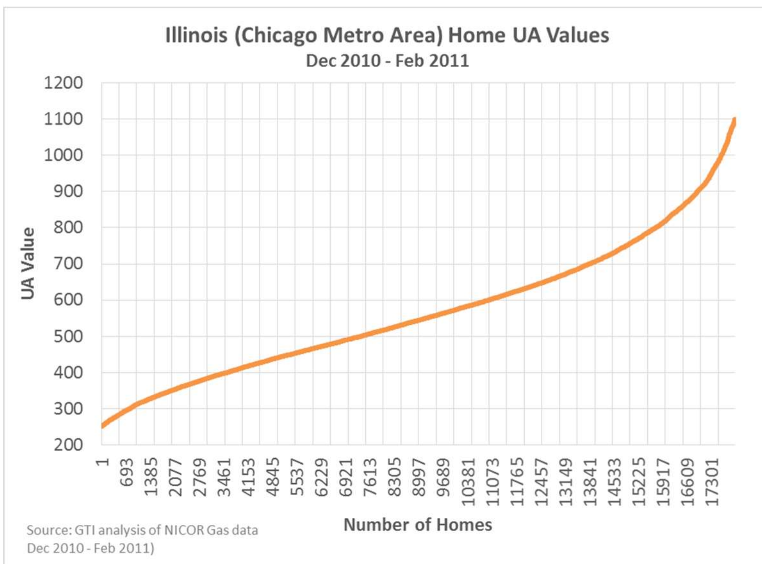


Figure 17: Distribution of UA Values for Illinois Homes (Chicago Metro Area)

Figure 18 shows the distribution of the steady-state and setback recover furnace capacity requirements for the nearly 18,000 homes in the Chicago metro area. An 80th percentile value for steady state and setback recovery operation is about 83,000 to 85,000 Btu/hour.

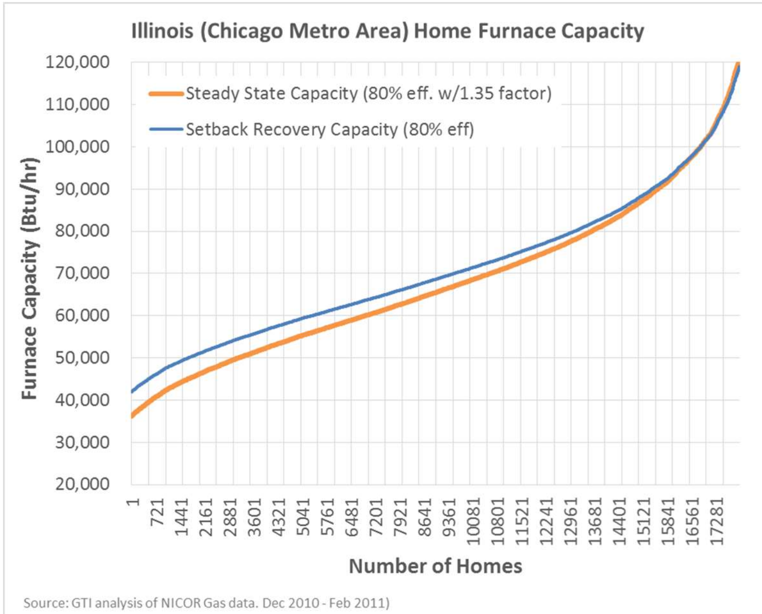


Figure 18: Distribution of Furnace Capacity for Illinois Homes (Chicago Metro Area)

Missouri (St. Louis Area) Homes

Figure 19 shows the results of the UA Values (Dec-Jan) calculation for this larger population of 2,235 St. Louis area homes (December 2008 – February 2009). In this data, the furnace efficiency was assumed to be 78% (these data were gas use prior to installing high-efficiency furnaces). The data in this figure excludes homes below UA Value 250 and above 1100 (less than 6.3% of all the homes in this dataset). Table 9 provides summary statistics on this population of St. Louis area homes. Using the relationship between UA Value (Dec-Feb) and net delivered energy required, GTI analysts calculated steady state and setback recovery furnace capacity requirements for 80% efficient units.

Table 9: Characteristics for Missouri (St. Louis Area) Homes

	UA Value (Dec-Feb)	Steady State Furnace Capacity With 1.35 DOE/ACCA Sizing Factor (Btu/hr, 80% efficiency)	Setback Recovery Furnace Capacity (Btu/hr, 80% efficiency)
80th Percentile	690	80,055	81,860
Average	552	66,284	69,336
Median	528	63,933	67,197
Standard Deviation	176	17,570	15,980

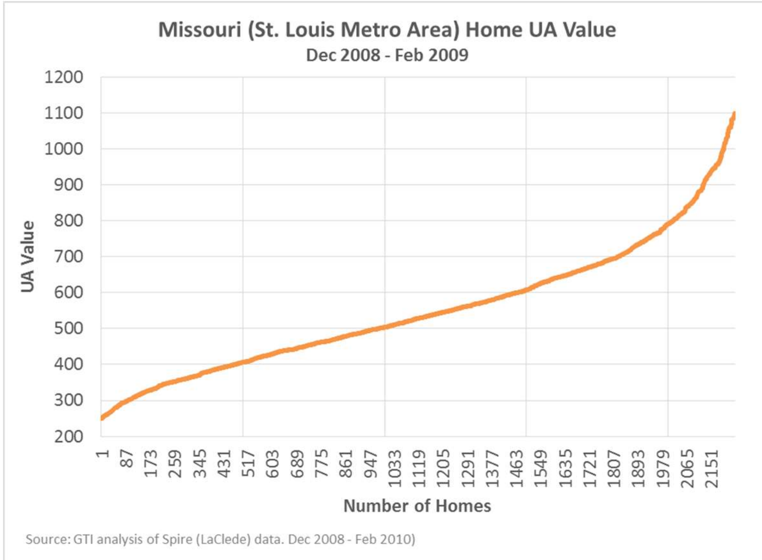


Figure 19: Distribution UA Values (Dec-Feb) for Missouri Homes (St. Louis area)

Figure 20 shows the distribution of the steady-state and setback recover furnace capacity requirements for the 413 homes in the St. Louis metro area. An 80th percentile value for steady state and setback recovery operation is about 80,000 to 82,000 Btu/hour.

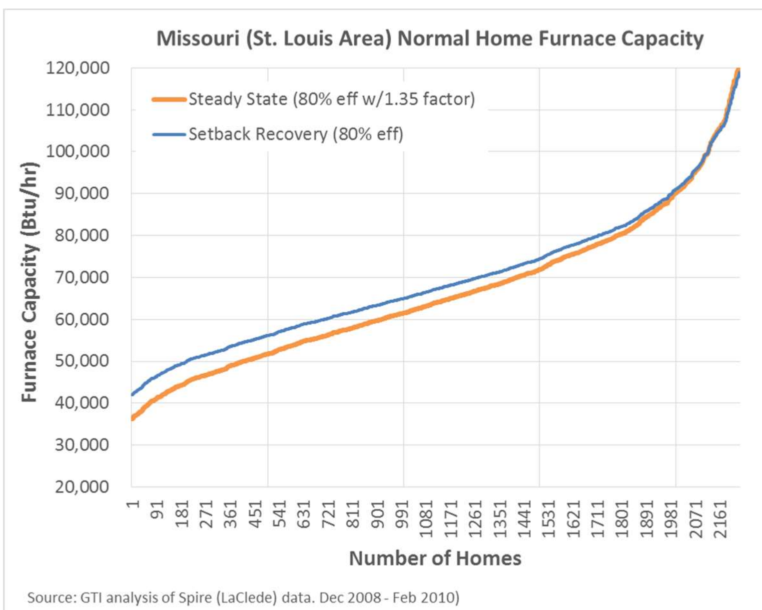


Figure 20: Distribution of Furnace Capacity for Missouri (St. Louis Area)

Minnesota (Minneapolis/St. Paul Area) Homes

Figure 21 shows the results of the UA Values (Dec-Jan) calculation for 413 homes in the Minneapolis/St. Paul area (December 2015 – February 2016). The data in this figure excludes homes below UA Value 250 and above 1100 (this is about 17% of the homes in this dataset). Table 10 provides summary statistics on this population of Minneapolis area homes. Using the relationship between UA Value (Dec-Feb) and net delivered energy required, GTI analysts calculated steady state and setback recovery furnace capacity requirements for 80% efficient units.

Table 10: Characteristics for Minnesota Homes (Minneapolis/St. Paul)

	UA Value (Dec-Feb)	Steady State Furnace Capacity With 1.35 DOE/ACCA Sizing Factor (Btu/hr, 80% efficiency)	Setback Recovery Furnace Capacity (Btu/hr, 80% efficiency)
80th Percentile	508	61,931	65,376
Average	416	52,774	57,048
Median	381	49263	53,855
Standard Deviation	139	13,812	12,562

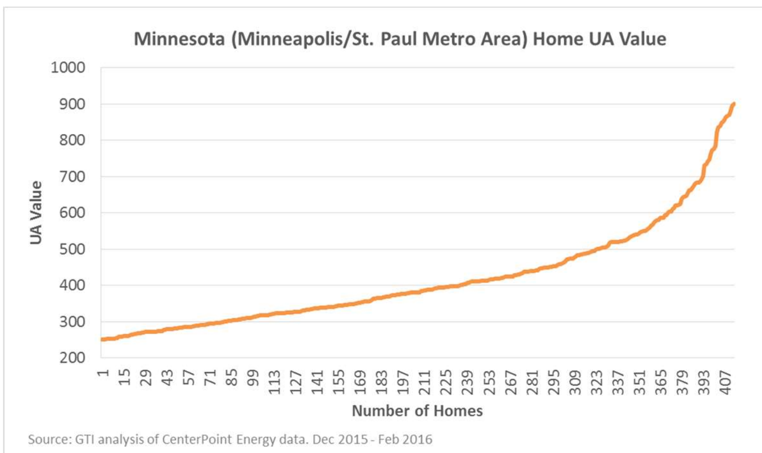


Figure 21: Distribution UA Values (Dec-Feb) for Minnesota Homes (Minneapolis/St. Paul)

Figure 22 shows the distribution of the steady-state and setback recover furnace capacity requirements for the 413 homes in the Minneapolis metro area. An 80th percentile value for steady state and setback recovery operation is about 62,000 to 65,000 Btu/hour.

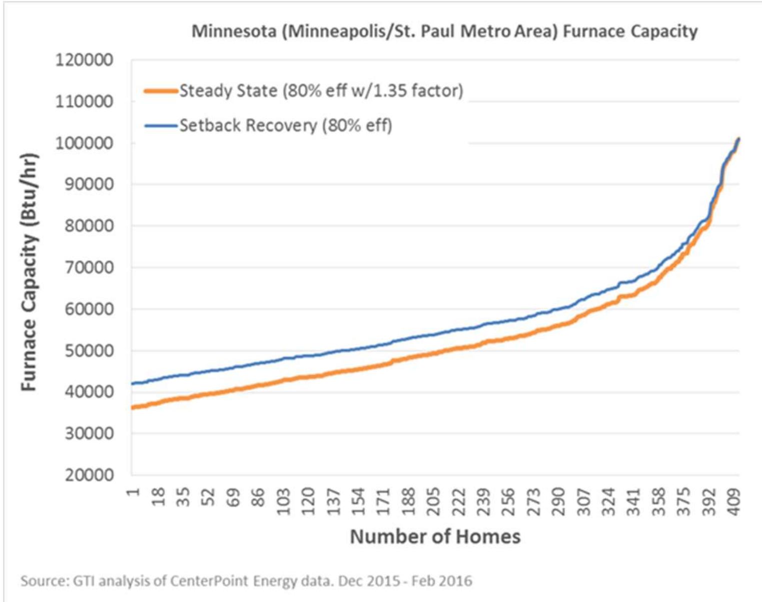


Figure 22: Distribution of Furnace Capacity for Minnesota Homes (Minneapolis/St. Paul)

The Minnesota data set, while relatively small, has uniquely low UA Values in relation to findings for the Chicago and St. Louis metro area. Counterintuitively, these results indicate average furnace sizing for steady state operation that are about 10,000 to 15,000 Btu/hour lower than typical homes in Chicago and St. Louis. This may reflect the nature of building codes in Minnesota that have promoted weatherized homes or a potential bias in this data set towards homes that have undergone a high level of weatherization. One further consideration is the winter of 2015-2016 was relatively warm, with total heating degree days that were 25.5% lower than the winter of 2013-2014. A colder winter would act to shift these curves upward and reduce the disparity. Additional data may be warranted to further investigate home construction and thermostat operation in Minnesota.

Arkansas (Little Rock Area) Homes

Figure 23 shows the results of the UA Values (Dec-Jan) calculation for 308 homes in the Little Rock, Arkansas area (December 2015 – February 2016). The data in this figure excludes homes below UA Value 250 and above 1100. This is about 28% of the homes in the dataset. Notably most of the excluded homes had UA Values above 1100. These results highlight the relative poor cold weather insulation attributes – and higher rates of heat loss – in these homes. This is a clear finding from the higher home UA Values. Table 10 provides summary statistics on this population of Arkansas homes. Using the relationship between UA Value (Dec-Feb) and net delivered energy required, GTI analysts calculated steady state and setback recovery furnace capacity requirements for 80% efficient units.

Table 11: Characteristics for Arkansas Homes (Little Rock Area)

	UA Value (Dec-Feb)	Steady State Furnace Capacity With 1.35 DOE/ACCA Sizing Factor (Btu/hr, 80% efficiency)	Setback Recovery Furnace Capacity (Btu/hr, 80% efficiency)
80th Percentile	897	100,717	100,652
Average	675	78577	80,141
Median	659	76,921	78,828
Standard Deviation	209	20,881	19,095

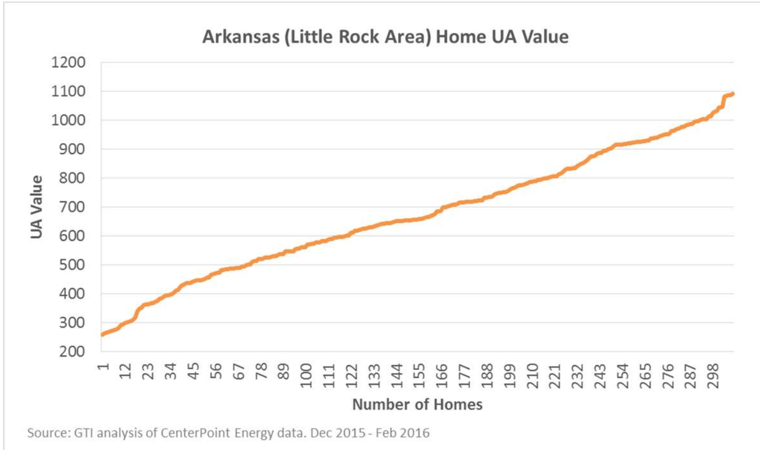


Figure 23: Distribution UA Values (Dec-Feb) for Arkansas Homes (Little Rock Area)

Figure 24 shows the distribution of the steady-state and setback recover furnace capacity requirements for the 308 homes in the Little Rock and surrounding area. An 80th percentile value for steady state and setback recovery operation is about 101,000 Btu/hour.

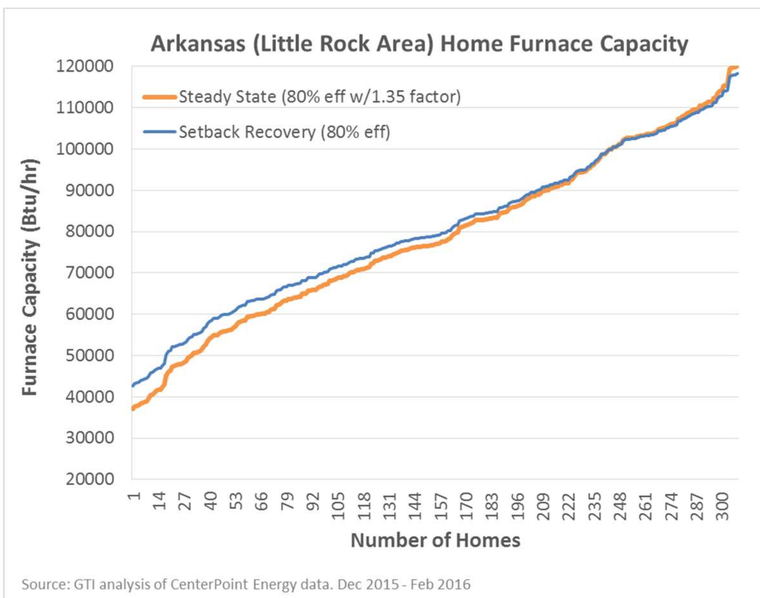


Figure 24: Distribution of Furnace Capacity for Arkansas Homes (Little Rock Area) Homes

The Arkansas data set is unique in the way it highlights higher UA Values for peak heating periods compared to information for the Chicago, St. Louis, and Minneapolis metro areas. Counterintuitively, these results indicate furnace sizing for steady state operation and setback recovery that are nearly 10,000 Btu/hour higher than typical homes in Chicago or St. Louis. This finding suggests that the building stock in Southern cooling-dominated may have lower levels of weatherization than the building stock in heating dominated Northern climate zones.

Oklahoma (Oklahoma City Area) Homes

Figure 25 shows the results of the UA Values (Dec-Jan) calculation for 125 homes in the Oklahoma City, Oklahoma area (December 2015 – February 2016). The data in this figure excludes homes below UA Value 250 and above 1100. These are about 14% of the homes in the dataset. Most of the excluded homes had UA Values above 1100. These results highlight the relative poor cold weather insulation attributes – and higher rates of heat loss – in these homes. This is a clear finding from the higher home UA Values. Table 10 provides summary statistics on this population of Oklahoma homes. Using the relationship between UA Value (Dec-Feb) and net delivered energy required, GTI analysts calculated steady state and setback recovery furnace capacity requirements for 80% efficient units.

Table 12: Characteristics for Oklahoma (Oklahoma City Area) Homes

	UA Value (Dec-Feb)	Steady State Furnace Capacity With 1.35 DOE/ACCA Sizing Factor (Btu/hr, 80% efficiency)	Setback Recovery Furnace Capacity (Btu/hr, 80% efficiency)
80th Percentile	860	97,035	97,303
Average	645	75,607	77,814
Median	610	72,105	74,629
Standard Deviation	210	20,916	19,023

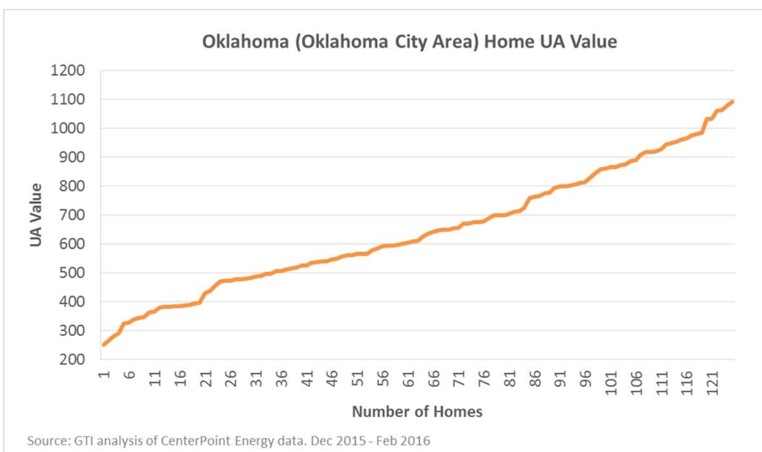


Figure 25: Distribution UA Values (Dec-Feb) for Oklahoma Homes (Oklahoma City Area)

Figure 26 shows the distribution of the steady-state and setback recover furnace capacity requirements for the 125 homes in the Oklahoma City and surrounding area. An 80th percentile value for steady state and setback recovery operation is about 97,000 Btu/hour.

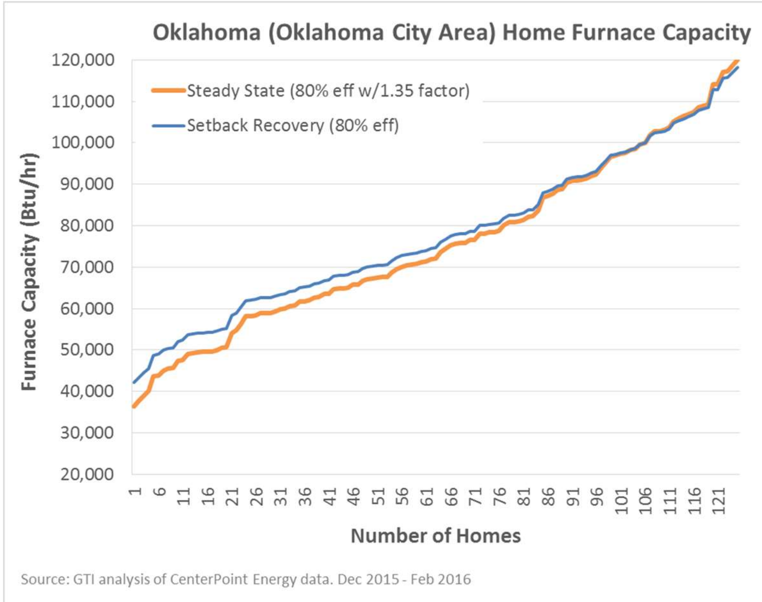


Figure 26: Distribution of Furnace Capacity for Oklahoma Homes (Oklahoma City Area)

The Oklahoma data set closely mirrors the Arkansas results and reinforce the nature of Southern home construction that points to the need for larger capacity furnaces during peak heating periods. As seen in the Arkansas data, homes in Oklahoma counterintuitively need average furnace sizing for steady state operation that are 10,000 Btu/hr higher than typical homes in Chicago or St. Louis; this number could be even higher taking into account thermostat setback recovery operation. This appears to clearly reflect the nature of the building stock in Southern climates and the lower level of weatherization.

Summary Furnace Sizing Results

For these five metropolitan and surrounding regions – Chicago, St. Louis, Minneapolis, Little Rock, and Oklahoma City – GTI analyzed over 21,000 homes to understand: (1) their peak space heating months natural gas use, (2) inferred home weatherization level through calculation of the home's UA Value, and (3) derived furnace capacity for steady-state and smart thermostat setback recovery operation.

Table 13 summarizes the results for the 21,059 homes with UA Values greater than 250 and less than 1100. The 80th percentile for steady state and setback recovery furnace capacity is around 83,000 Btu/hour to 85,000 Btu/hour.

Table 13: Summary Empirically Derived Furnace Sizing Results

	UA Value (Dec-Feb)	**Steady State Furnace Capacity With 1.35 DOE/ACCA Sizing Factor (Btu/hr, 80% efficiency)**	**Setback Recovery Furnace Capacity (Btu/hr, 80% efficiency)**
80th Percentile	721	83,099	84,629
Average	565	67,609	70,541
Median	540	65,147	68,301
Standard Deviation	185	18,486	16,813

Table 14 provides a summary of all the monthly natural gas use data and the subset (91.4%) of information included in the above analysis. GTI set a range of UA Values from 250 to 1100 as being representative of conventional single-family homes. Values below this are more probable to be multi-family residences such as apartment and condominium units which would not need larger furnaces. Values above UA Value 1100 are likely to include much larger residences which may require bigger (or multiple) furnaces. By restricting the data range to UA Values of 250 to 1100, there is a more uniform and representative population of single-family homes likely to exist. The data demonstrate exclusions were balanced between the upper and lower ends of the entire population of homes.

Table 14: Data Inclusion and Exclusion

	Excluded Data UA Value 50 to <250	**Included Data UA Value 250 to <1100**	**Excluded Data UA Value 1100 to <3000**
Illinois	823	17,978	777
Missouri	78	2,235	71
Minnesota	90	413	4
Arkansas	20	308	92
Oklahoma	9	125	13
Total	**1,020**	**21,059**	**957**
% of Total	4.4%	91.4%	4.2%

Figure 27 shows the overall distribution of steady-state and setback recovery furnace capacity ratings. As noted, the 80th percentile range for steady-state and setback recovery furnace capacity is around 83,000 to 85,000 Btu/hour.

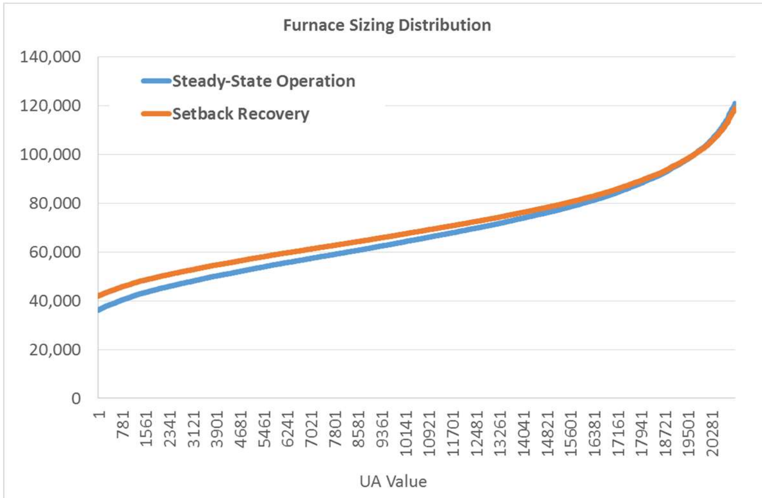


Figure 27: Distribution of Furnace Capacity for Steady-State and Setback Recovery Operation

The results of this analysis indicate there are strong regional differences in building construction. Homes in Minnesota, for example, appear to have much higher levels of weatherization than homes in Arkansas and Oklahoma. This leads to a counterintuitive result that homes in Arkansas and Oklahoma actually require, on average, larger furnaces than are needed in Minnesota to meet their peak heating month requirements. UA Values of homes in the South are considerably higher than in Minnesota and require larger furnaces during peak heating periods to compensate for the greater rate of building energy losses.

Table 15 and Figure 28 shows these findings. Compared to Minnesota homes, residential buildings in Chicago use 57% more gas per HDD, 77% more in St. Louis and Oklahoma, and 133% more in Arkansas. Regional building practices clearly have a substantial impact on furnace sizing requirements and lead to findings that counterintuitively indicate many Southern homes in climate zone 3 need larger furnaces to meet their peak heating needs. More Minnesota data, along with data from other cities in climate zone 6 or 7, would be helpful to confirm the nature of home construction in those colder climate zones.

Table 15: Summary Regional Findings

	Average UA Value (Dec-Feb)	80th Percentile Setback Recovery Operation (Btu/hour)	Ratio of Dec-Feb Space Heating Use to HDD	Ratio Relative to Minnesota Homes	Dec-Feb Space Heating Degree Days
Minnesota	416	65,376	0.0957	1.0000	3690
Illinois	568	83,353	0.1505	1.5734	3561
Missouri	552	81,860	0.1697	1.7736	2835
Oklahoma	645	97,303	0.1711	1.7882	1438
Arkansas	675	100,652	0.2233	2.3340	1151

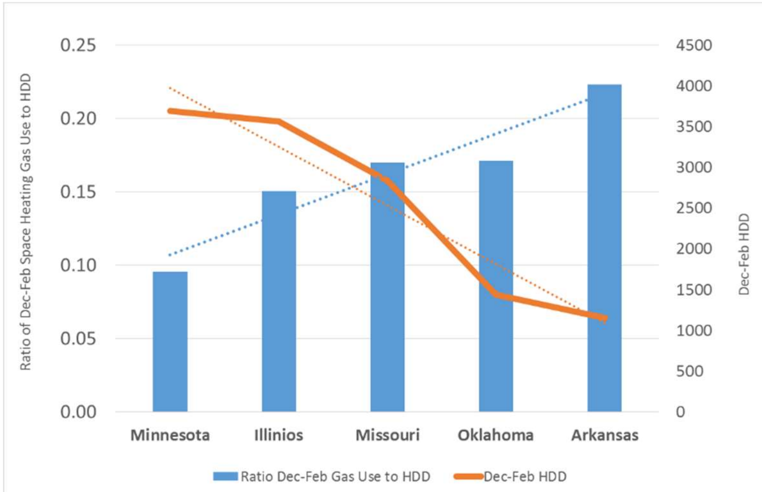


Figure 28: Regional Differences In Specific Peak Home Heating Rates

Conclusions

The findings from this report demonstrate that homes vary considerably in their peak space heating needs. The most accurate predictor of annual and peak space heating energy needs is captured by home UA Value. Home square footage, by comparison, has a relatively weak correlation.

Home occupants can differ considerably in their lifestyle choices used for space heating their homes. This includes a wide distribution in nominal thermostat setpoint values – this can differ by over 10ºF – as well as the way in which they use programmable or smart thermostats. The use of smart thermostats necessitates greater furnace capacity to enable timely recovery of indoor temperature setting after larger (over 2 ºF) thermostat setbacks during overnight periods or during the day if the home is unoccupied.

Table 16 summarizes the furnace size requirements for the overall dataset as well as the regional breakdown. The 80th percentile values for steady-state and setback recovery operation was in the range of 83,000 Btu/hour to 85,000 Btu/hour. This should satisfactorily meet the needs of most natural gas customers.

Table 16: Summary Furnace Capacity Requirements (80% Efficient Furnace)

All Five Regions	**Steady-State Operation (Btu/hour) With 1.35 DOE/ACCA Sizing Factor**	**Setback Recovery Operation (Btu/hour)**
80th Percentile Capacity	83,070	84,627
Average Capacity	67,607	70,538
Median Capacity	65,147	68,031
Regional Findings	80th Percentile Steady-State Operation (Btu/hour)	80th Percentile Setback Recovery Operation (Btu/hour)
Minnesota	61,931	65,376
Missouri	80,055	81,860
Illinois	83,353	84,859
Oklahoma	97,035	97,303
Arkansas	100,717	100,652

Perhaps counterintuitively, furnace sizing requirements increased for homes located in Southern, cooling-dominated regions (e.g., Arkansas and Oklahoma). The data give clear findings that these homes exhibit lower levels of weatherization that result in higher levels of building heat loss during peak heating months of December through February. This necessitates higher than anticipated peak furnace capacity ratings in Southern climate zones.

Additional research would help evaluate the regional differences in home construction and the significant impact on peak furnace capacity requirements. These findings indicate that homes in Minnesota in particular have an impressive level of weatherization. Additional research would be helpful to confirm this finding and to ascertain whether these results apply to other DOE/IECC climate zone 6 or 7 regions (or are they specific to Minnesota's building codes).

The findings about the poor weatherization attributes of homes in Southern, cooling-dominated regions would benefit from extension of this analysis to other states to confirm the findings.

Based upon this analysis, it appears evident a 55,000 Btu/hr furnace is insufficient for meeting the space heating needs of the vast majority of single-family homes in the U.S. – cold climate and more temperate climate zones (due to the poor weatherization attributes in those regions). This type of unit could be marginally satisfactory for smaller homes or larger "tight" homes with UA Values below about 400. Even for these types of homes, occupants could experience hours where such a unit would be undersized to meet steady-state heating requirements; this compromise in performance and comfort becomes would be more accentuated during smart thermostat setback recovery periods.

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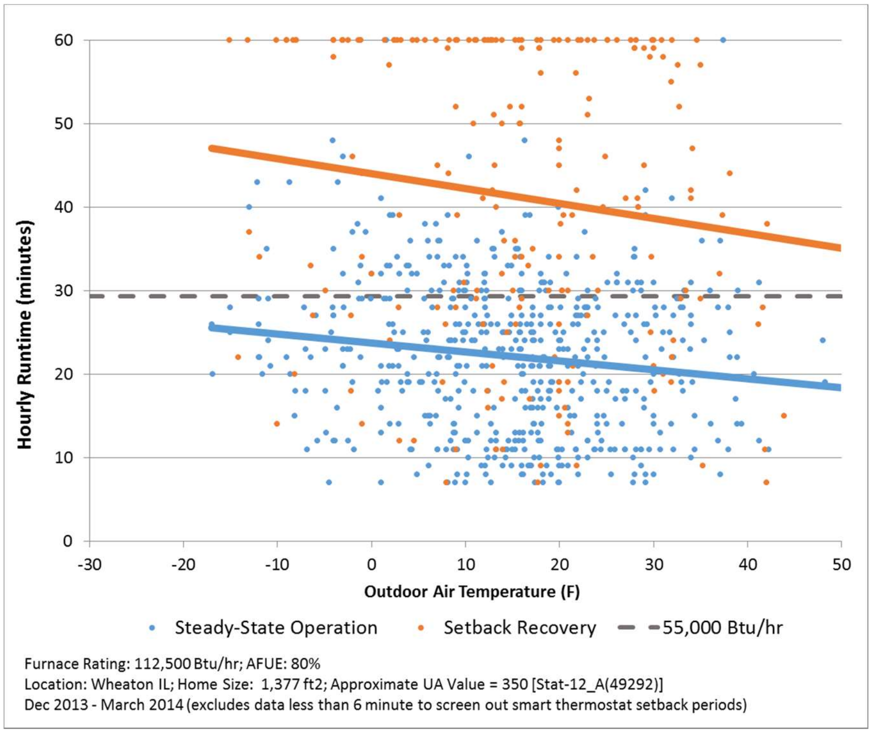
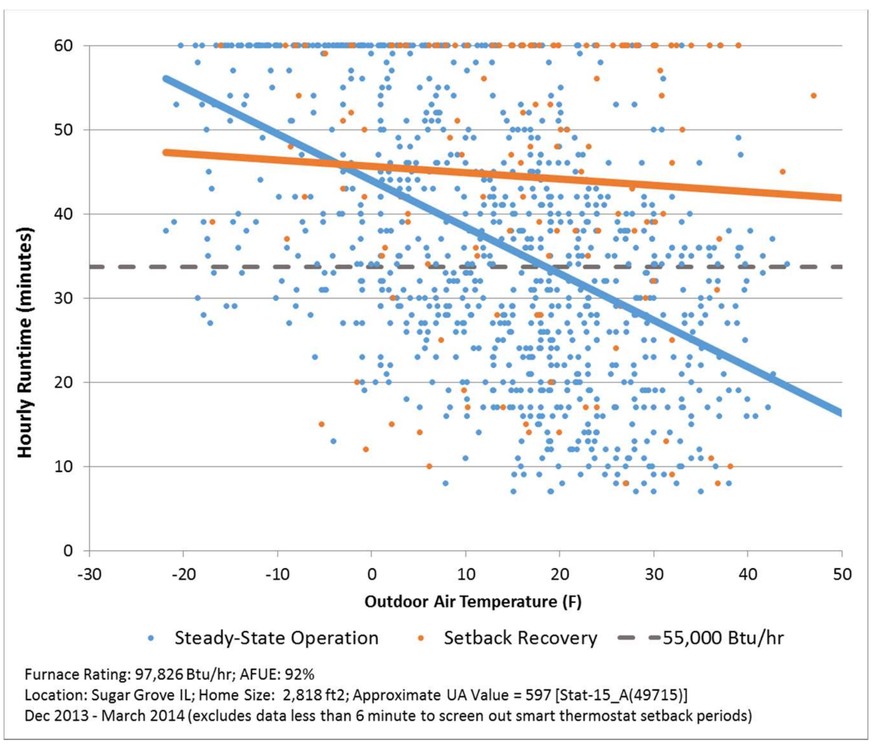
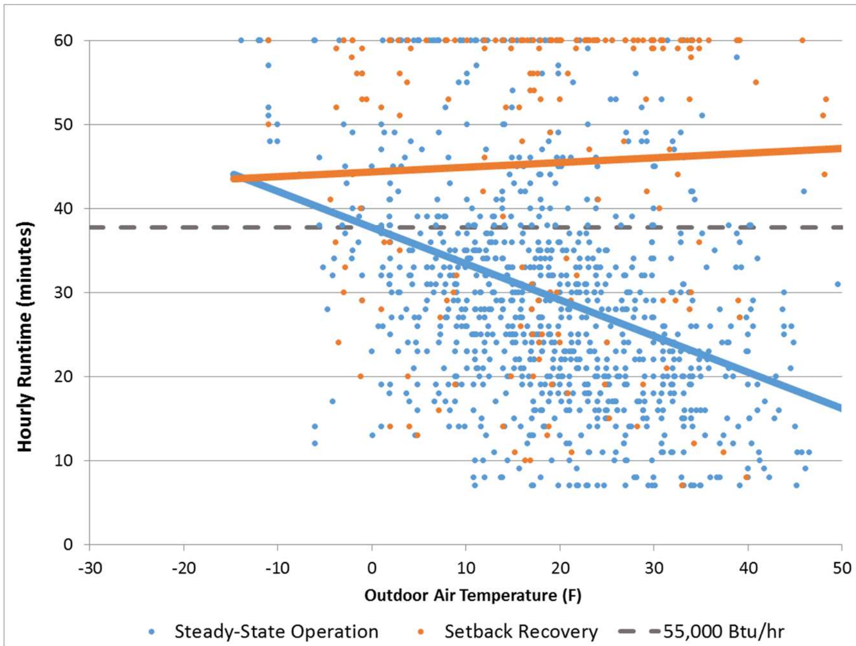
Appendix A. Detailed Furnace Run Time Plots (21 Homes)

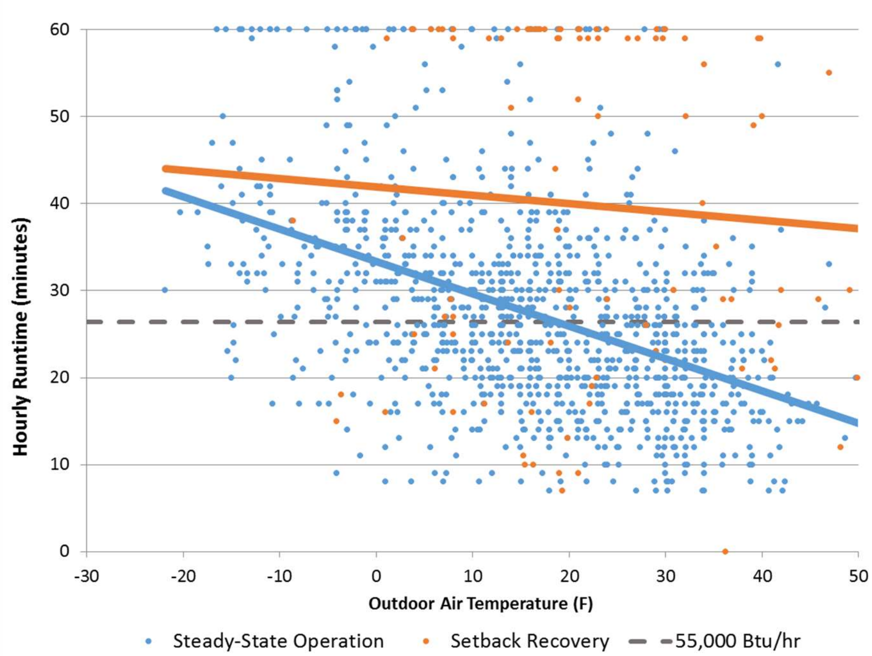
Furnace run time data are included in this appendix. Each graph is annotated with information identifying the home, home size (ft[2]), furnace size, furnace efficiency, and UA Value. Data cover operation in the Chicago metropolitan area from December 1, 2013 – March 19, 2014.



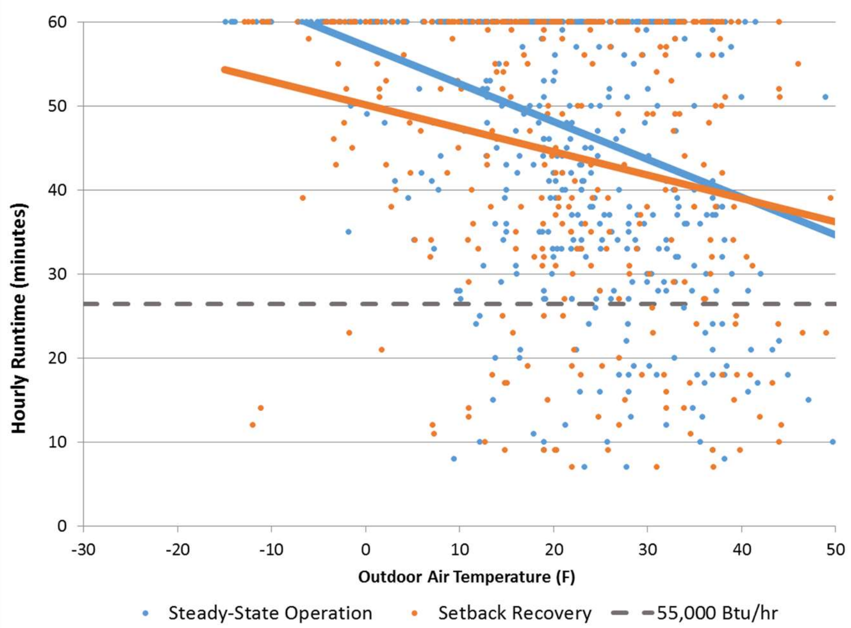




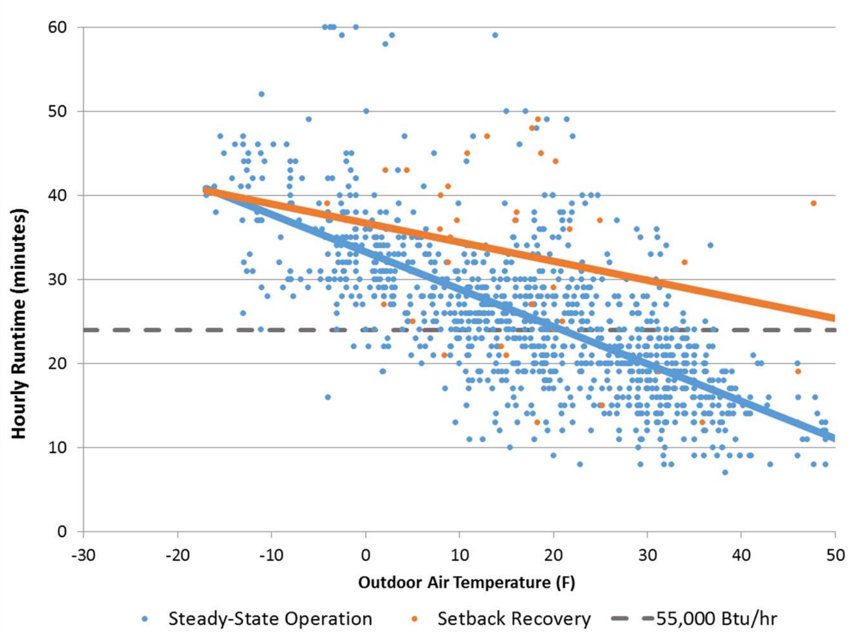
Furnace Rating: 87,500 Btu/hr; AFUE: 80%
Location: Hillside IL; Home Size: 1,073 ft2; Approximate UA Value = 521 [Stat-28_A(49716)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



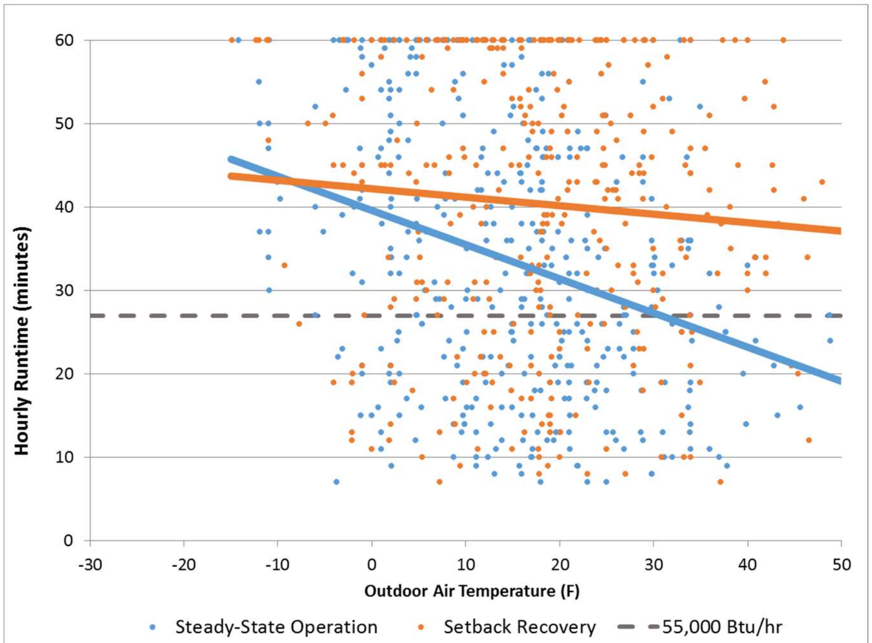
Furnace Rating: 125,000 Btu/hr; AFUE: 80%
Location: Montgomery IL; Home Size: 2,750 ft2; Approximate UA Value = 567 [Stat-29_A(49801)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



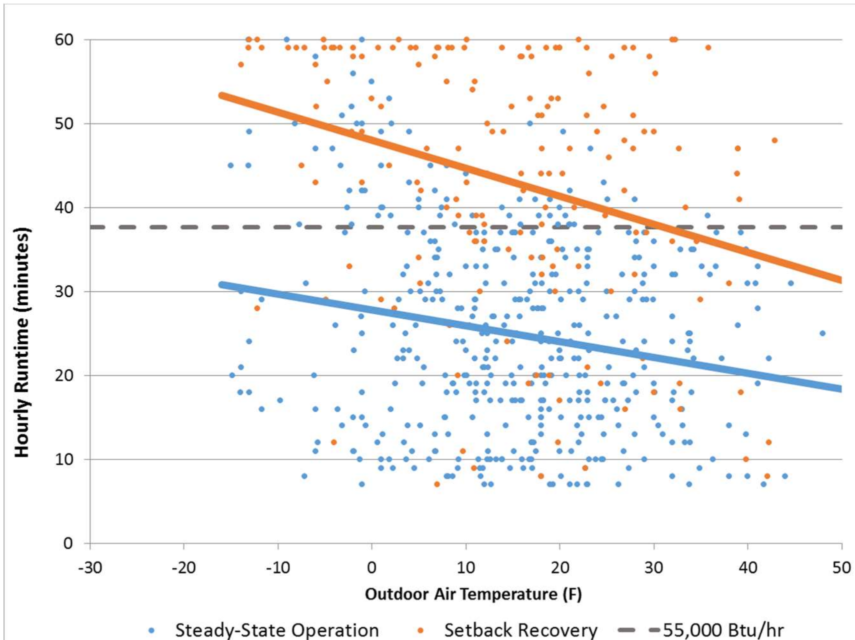
Furnace Rating: 125,000 Btu/hr; AFUE: 80%
Location: South Holland IL; Home Size: 1,461 ft2; Approximate UA Value = 966 [Stat-37_A(49826)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



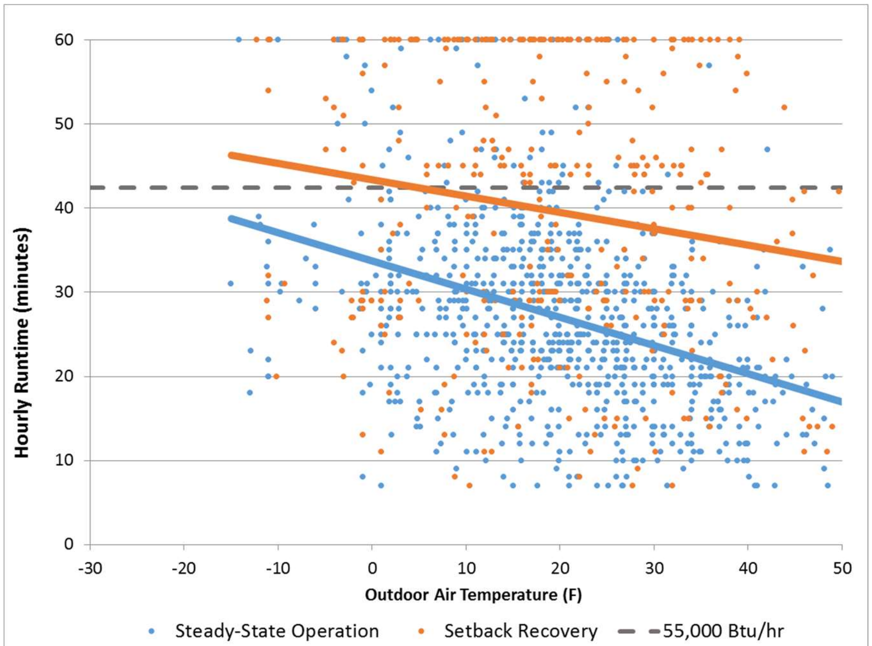
Furnace Rating: 137,500 Btu/hr; AFUE: 80%
Location: Romeoville IL; Home Size: 2,254 ft2; Approximate UA Value = 662 [Stat-39_A(49749)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



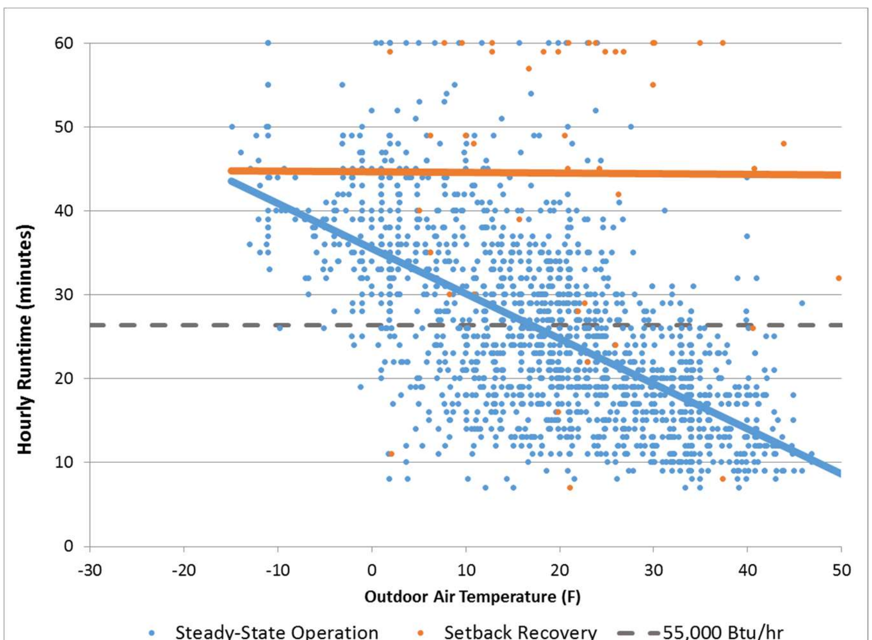
Furnace Rating: 122,222 Btu/hr; AFUE: 90%
Location: Arlington Heights IL; Home Size: 3,002 ft2; Approximate UA Value = 517 [Stat-40_A(49366)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



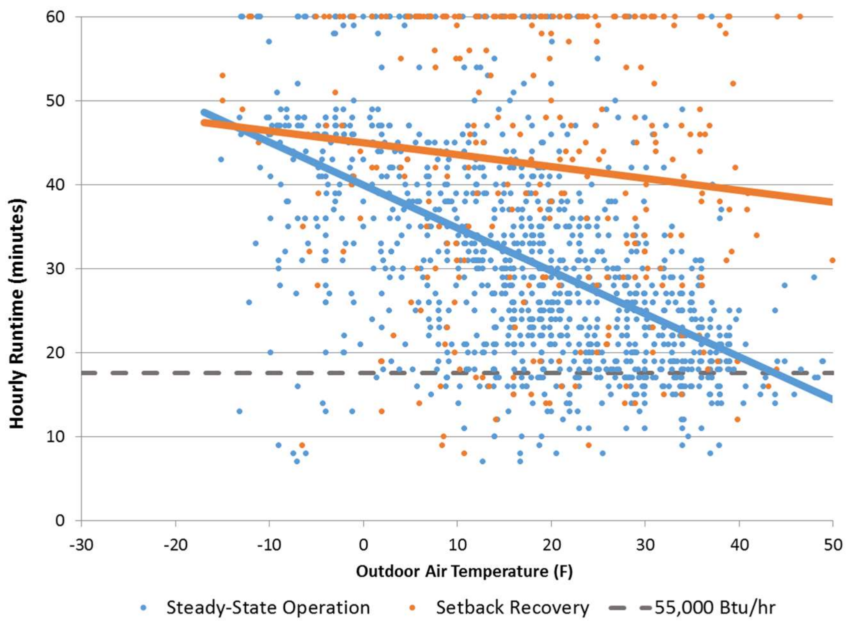
Furnace Rating: 87,500 Btu/hr; AFUE: 80%
Location: Volo IL; Home Size: 1,656 ft2; Approximate UA Value = 268 [Stat-42_A(49713)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



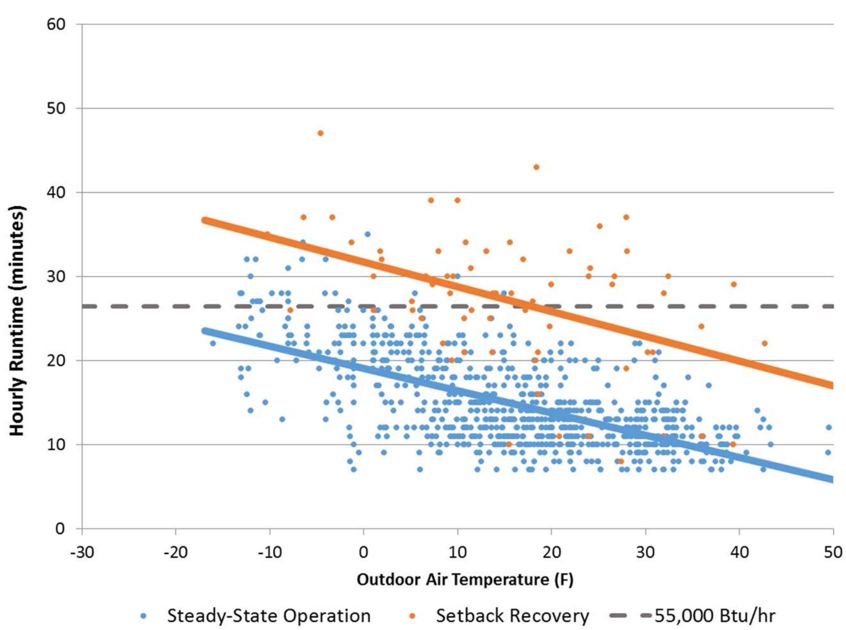
Furnace Rating: 77,778 Btu/hr; AFUE: 90%
Location: Arlington Heights IL; Home Size: 1,728 ft2; Approximate UA Value = 1062 [Stat-43_A(49615)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



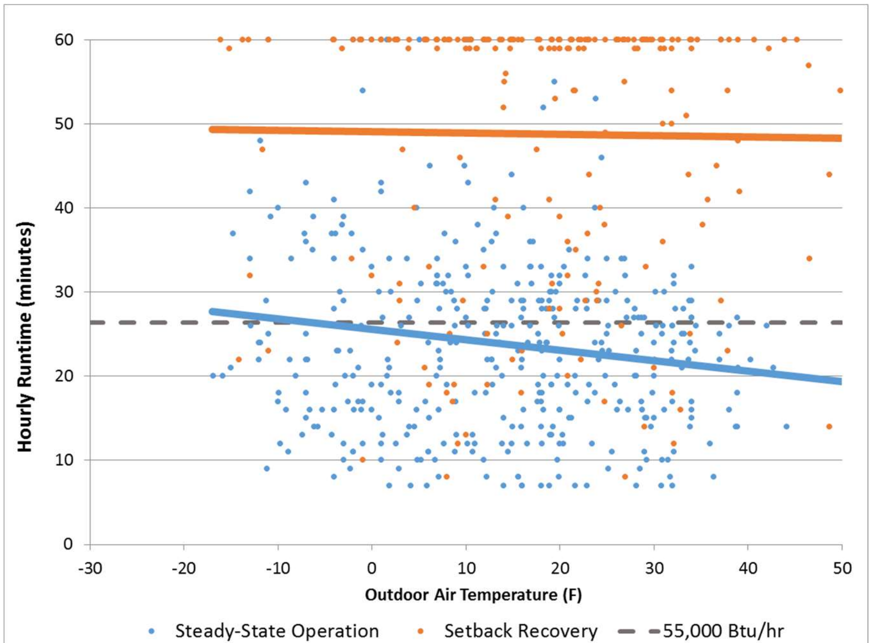
Furnace Rating: 125,000 Btu/hr; AFUE: 80%
Location: Buffalo Grove IL; Home Size: 2,018 ft2; Approximate UA Value = 616 [Stat-45_A(49408)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



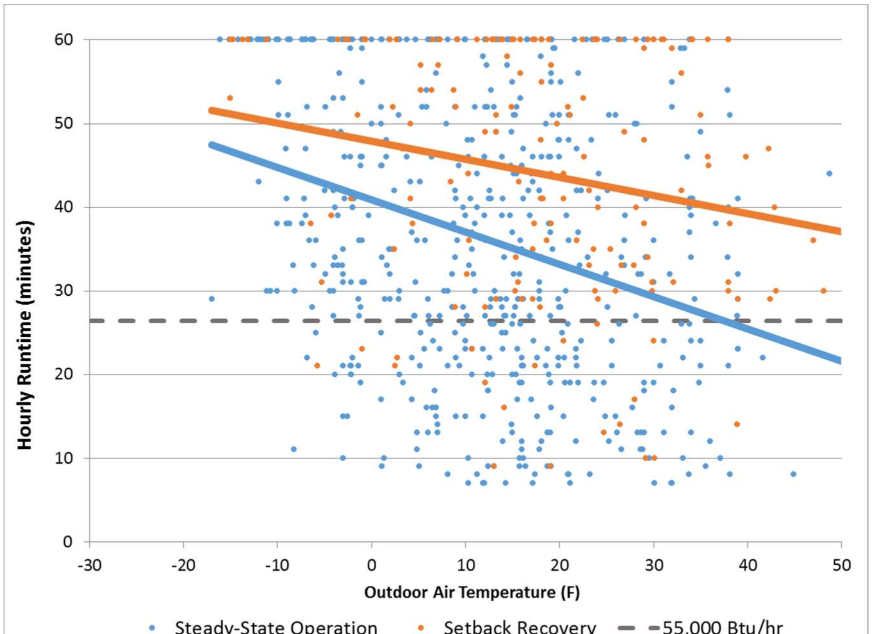
Furnace Rating: 187,500 Btu/hr; AFUE: 80%
Location: Carpentersville IL; Home Size: 3,264 ft2; Approximate UA Value = 1127 [Stat-46_A(49637)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



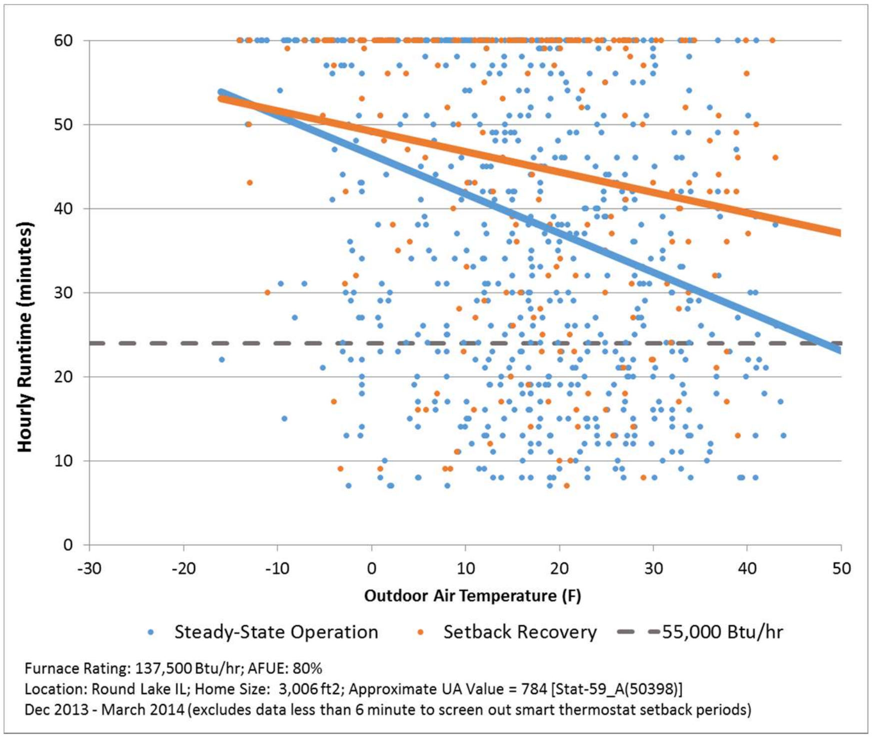
Furnace Rating: 125,000 Btu/hr; AFUE: 80%
Location: Plainfield IL; Home Size: 1,510 ft2; Approximate UA Value = 301 [Stat-49_A(49506)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)

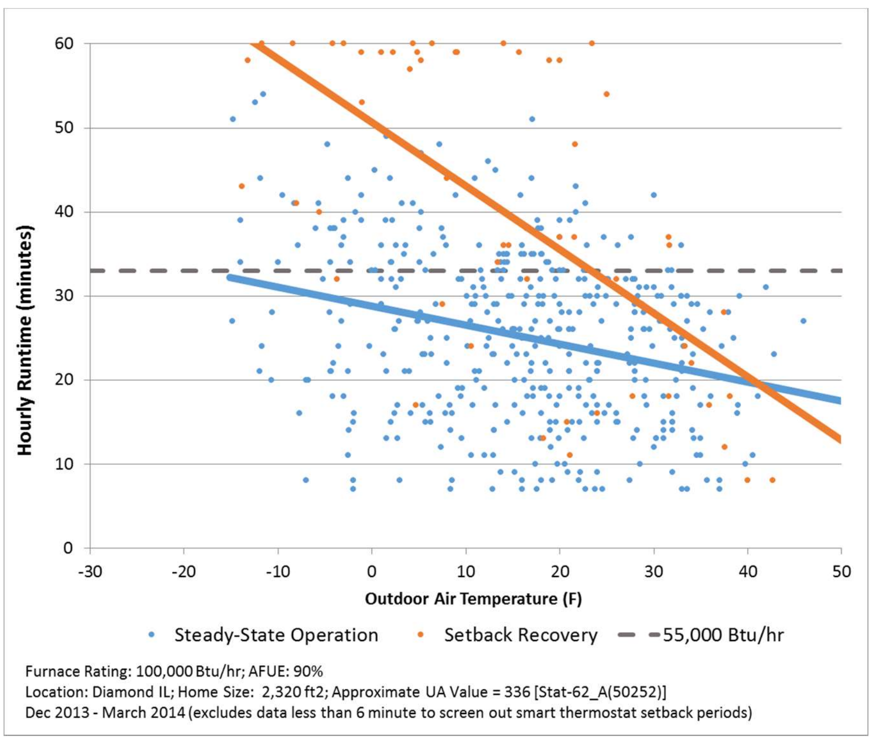


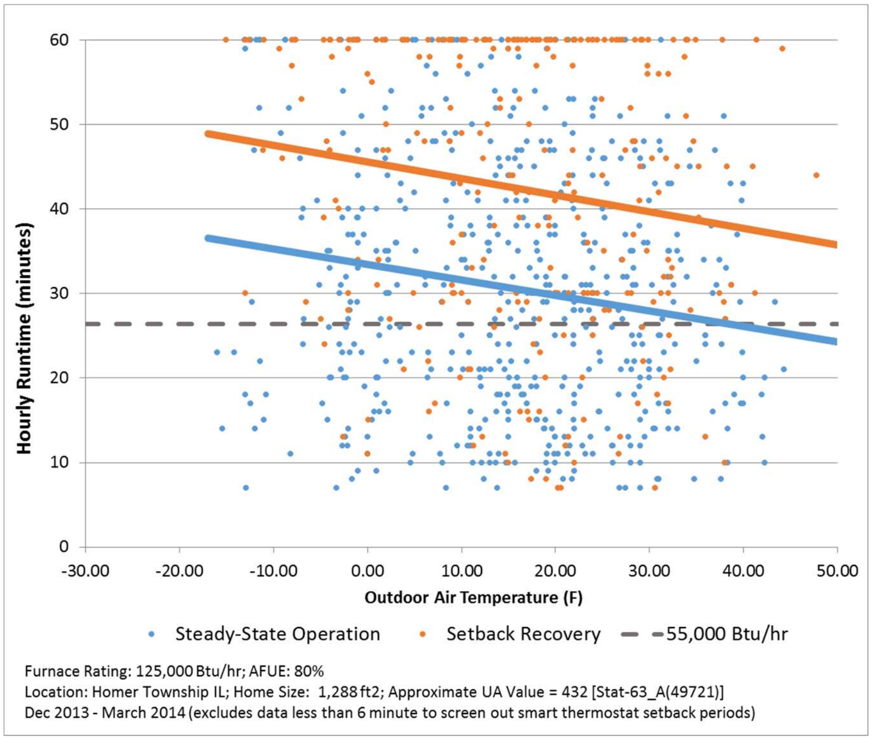
Furnace Rating: 125,000 Btu/hr; AFUE: 80%
Location: Bartlett IL; Home Size: 2,040 ft2; Approximate UA Value = 408 [Stat-51_A(49009)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)

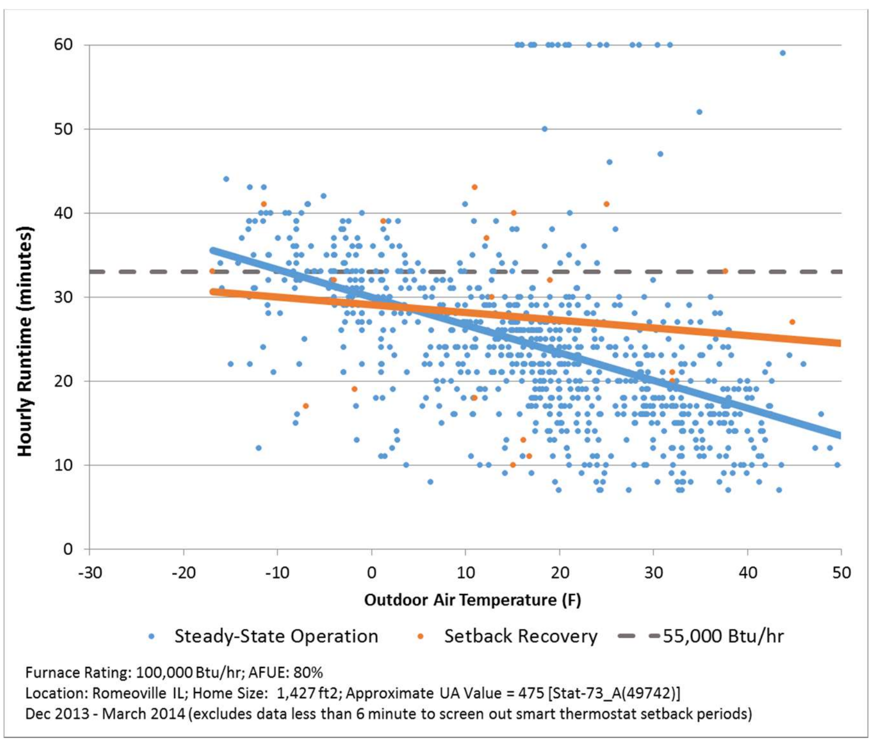


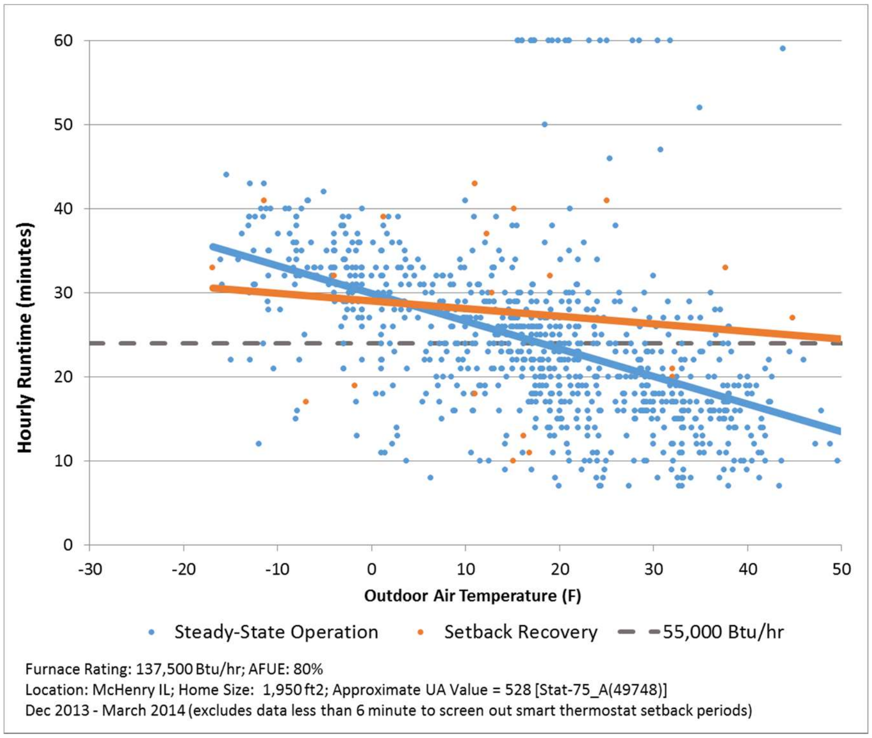
Furnace Rating: 125,000 Btu/hr; AFUE: 80%
Location: Naperville IL; Home Size: 2,012 ft2; Approximate UA Value = 706 [Stat-58_A(49762)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)


Hourly Runtime (minutes)
Outdoor Air Temperature (F)
Steady-State Operation
Setback Recovery
55,000 Btu/hr
Furnace Rating: 137,500 Btu/hr; AFUE: 80%
Location: Round Lake IL; Home Size: 3,006 ft2; Approximate UA Value = 784 [Stat-59_A(50398)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)

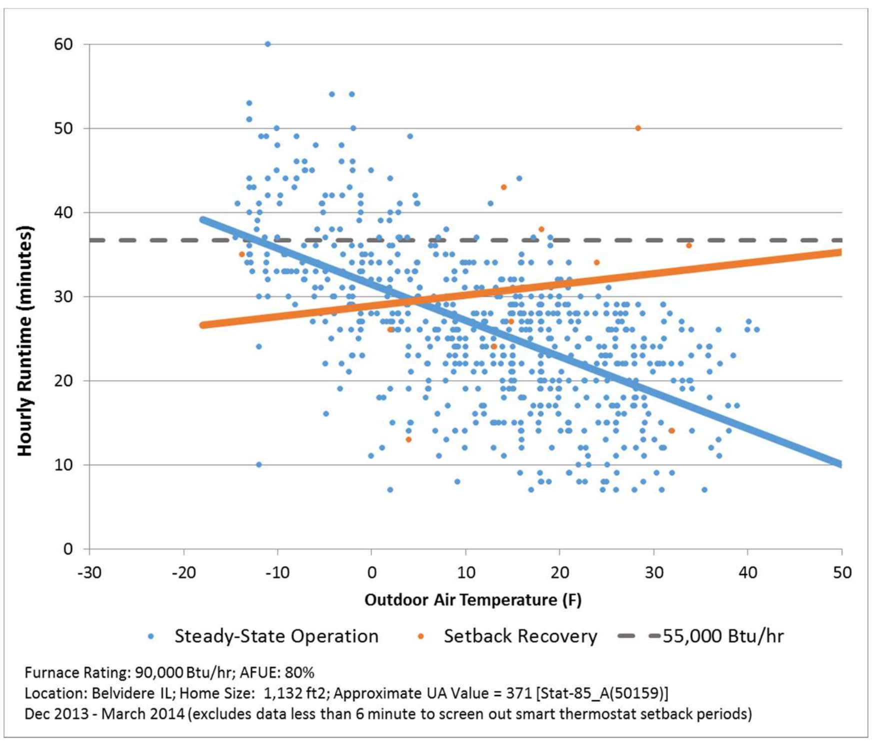

Hourly Runtime (minutes)
Outdoor Air Temperature (F)
Steady-State Operation
Setback Recovery
55,000 Btu/hr
Furnace Rating: 100,000 Btu/hr; AFUE: 90%
Location: Diamond IL; Home Size: 2,320 ft2; Approximate UA Value = 336 [Stat-62_A(50252)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)


Hourly Runtime (minutes)
Outdoor Air Temperature (F)
Steady-State Operation
Setback Recovery
55,000 Btu/hr
Furnace Rating: 125,000 Btu/hr; AFUE: 80%
Location: Homer Township IL; Home Size: 1,288 ft2; Approximate UA Value = 432 [Stat-63_A(49721)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)

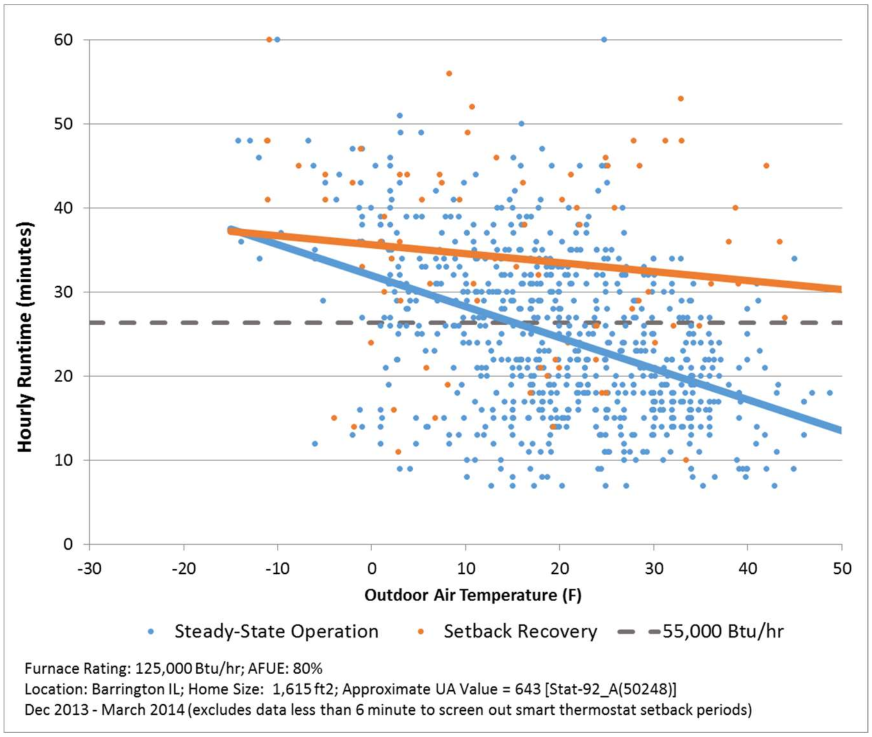

Hourly Runtime (minutes)
Outdoor Air Temperature (F)
Steady-State Operation
Setback Recovery
55,000 Btu/hr
Furnace Rating: 100,000 Btu/hr; AFUE: 80%
Location: Romeoville IL; Home Size: 1,427 ft2; Approximate UA Value = 475 [Stat-73_A(49742)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



Hourly Runtime (minutes)
Outdoor Air Temperature (F)
Steady-State Operation
Setback Recovery
55,000 Btu/hr
Furnace Rating: 137,500 Btu/hr; AFUE: 80%
Location: McHenry IL; Home Size: 1,950 ft2; Approximate UA Value = 528 [Stat-75_A(49748)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)



Hourly Runtime (minutes)
Outdoor Air Temperature (F)
Steady-State Operation
Setback Recovery
55,000 Btu/hr
Furnace Rating: 90,000 Btu/hr; AFUE: 80%
Location: Belvidere IL; Home Size: 1,132 ft2; Approximate UA Value = 371 [Stat-85_A(50159)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)


60
50
40
30
20
10
0
Hourly Runtime (minutes)
-30
-20
-10
0
10
20
30
40
50
Outdoor Air Temperature (F)
Steady-State Operation
Setback Recovery
55,000 Btu/hr
Furnace Rating: 125,000 Btu/hr; AFUE: 80%
Location: Barrington IL; Home Size: 1,615 ft2; Approximate UA Value = 643 [Stat-92_A(50248)]
Dec 2013 - March 2014 (excludes data less than 6 minute to screen out smart thermostat setback periods)