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Energy Savings From System Efficiency Improvements in Iowa's HVAC SAVE Program

S. Yee, J. Baker, L. Brand, and J. Wells
Partnership for Advanced Residential Retrofit

August 2013

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Definitions

ACCA	Air Conditioning Contractors of America
AFUE	Annual fuel utilization efficiency
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Btu	British thermal unit
CFM	Cubic feet per minute
ESP	External static pressure
HDD	Heating degree day
HVAC	Heating, ventilating, and air-conditioning
i.w.c.	Inches of water column
MEEA	Midwest Energy Efficiency Alliance
MBtu	Million British thermal units
NCI	National Comfort Institute
SAVE	System Adjusted & Verified Efficiency

Acknowledgments

PARR would like to thank Energy Stewards International and Cenergy for the collection of the data used in this project.

Executive Summary

The objective of the Iowa HVAC System Adjusted and Verified Efficiency (SAVE) program is to train contractors to measure installed system efficiency as a diagnostic tool that can then be used to reduce space heating and cooling energy consumption. For heating system performance, SAVE provides training in energy measurement tools, techniques used to tune furnaces, and procedures to reduce losses from duct distribution systems. Through a system efficiency approach, the program ensures that the homeowner achieves the energy reduction target for the home rather than simply performing a tune-up on the furnace or having a replacement furnace added to a leaky system. This report uses pre- and post-system upgrade data to analyze the energy savings associated with Iowa's HVAC SAVE program for space heating.

The research conducted here first examined baseline energy usage from a sample of 48 existing homes, before any repairs or adjustments were made, to calculate an average energy savings potential and to determine which system deficiencies were prevalent. Test procedures used in the SAVE program consisted of measuring airflow, static pressure, and temperature across several components and the whole system to determine how well the furnace was performing compared to the manufacturer's specifications and where the losses were occurring. After an initial assessment, duct distribution systems were sealed and insulated and in some cases additional drops were added from the return duct to the furnace to improve airflow.

The results of the baseline study of 48 homes found that on average about 10% of the space heating energy available from the furnace was not reaching the conditioned space. Thirty-one of the 48 homes were identified as having a return duct that was too small to meet the required airflow across the heat exchanger, while 43 of the 48 showed that the static pressure across the filter significantly reduced the airflow due to face area, blockage, or improper selection.

In the second part of the project, the team examined a sample of 10 homes that had completed the initial evaluation for more in-depth study. In these homes, the furnaces were tuned or replaced and duct systems were modified. Four homes had equipment replacement and duct upgrades, and six homes had system tune-ups for both furnaces and ducts.

For these 10 homes, the diagnostic data show that it is possible to deliver up to 23% more energy from the furnace to the conditioned space by doing system tune-ups (furnaces and ducts) with or without upgrading the furnace. The increase in system efficiency from this study also varied significantly, but it appears from the results that it is possible to deliver 80%–90% of the heat generated by the furnace to the conditioned space. Replacing the furnace provides additional energy reduction. The findings of this study indicate that residential heating and cooling equipment should be tested and improved as a system rather than as a collection of individual components.

1 Introduction and Background

The installed performance of natural gas furnaces is dependent on the rated annual fuel utilization efficiency (AFUE) of the furnace, the skill of the installation contractor, the degree to which the furnace has aged or drifted off its initial settings, and the condition of the duct distribution system. Although federal, state, and utility programs have increased the market penetration of residential high efficiency furnaces, there is evidence that the potential energy savings resulting from higher efficiency equipment are not being realized in the field (Walker and Modera 1998). A possible explanation for these lost savings is that one or more of the key dependencies mentioned above are suboptimal. For the furnace itself, the airflow setting, fuel input rate, and burner performance can all have an impact on how well the furnace performs in the field. Low airflow across the heat exchanger can have a number of negative consequences for the performance of a furnace, including cycling on high limit and poor heat transfer. Low airflow may be caused by improperly designed distribution systems, overly restrictive filters, dirty evaporator coils, and incorrectly set fan speeds. Some of these causes are simple to correct and some require extensive renovation of the ductwork. Contractor training in diagnostics and repair is a critical success factor in optimum system performance.

To address these challenges, the Midwest Energy Efficiency Alliance (MEEA), in partnership with Energy Stewards International, developed a program that allows heating, ventilation, and air conditioning (HVAC) contractors to easily diagnose the performance of a furnace in-situ. This training program and contractor certification is named HVAC SAVE: System Adjustment and Verified Efficiency. The HVAC SAVE program was developed by MEEA to train HVAC contractors in the skills necessary to determine in-place efficiency of functioning HVAC systems. Energy Stewards International has been training HVAC professionals for many years on how contractors can use static pressures, system temperatures, and airflows to identify existing system deficiencies, allowing them to make targeted repairs or adjustments. These principles are taught over the course of a two-day class, described in Appendix A, which prepares contractors to implement these diagnosis and improvement practices on new and existing systems. The format of the class is a combination of classroom instruction using PowerPoint presentations, as well as white-board diagrams, explanations and examples, hands-on testing modules, and interactive workbook exercises to prepare contractors to integrate these concepts into their regular business activities. Classes are either held at a location with working systems available for testing or Energy Stewards International brings a functioning demonstration kit to allow the air diagnostic concepts and procedures to be demonstrated on a live model "system."

The target audience for this course is HVAC technicians, installers, designers, and business owners. The curriculum provides for approximately 15 hours of total course material. At the conclusion of the second day, students are given a certification exam. Upon successful completion of the exam students are awarded the SAVE certification from MEEA and the National Comfort Institute (NCI). Using these methods MEEA and NCI have trained roughly 600 HVAC contractors across the state of Iowa to date, as shown in Figure 1.

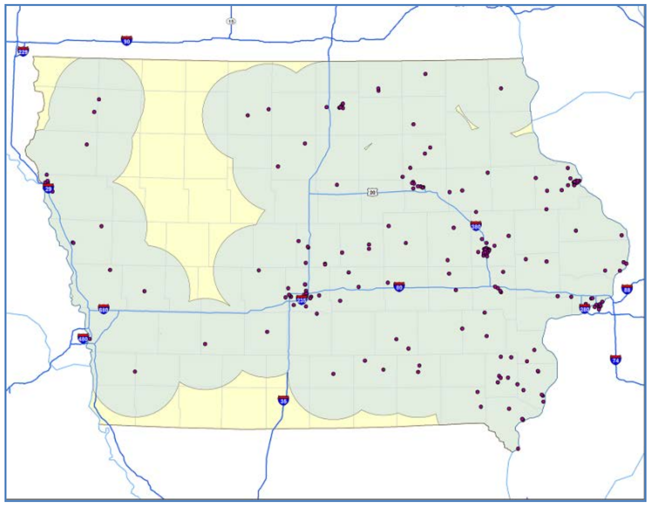

Figure 1. Map of trained contractors (circles represent 50-mi radius)

HVAC SAVE aims to have contractors take the information they have learned in the classroom and translate it into to energy savings in the field. Currently the market for system evaluations and improvements is limited. To address this issue, the program offers a financial incentive from the State of Iowa to trained contractors when they evaluate the performance of any new furnace installation by recording static pressures, temperatures, system airflows, and fuel input—putting their training into practice. In order to be eligible for this rebate, the furnace must be installed and performing at or near the manufacturer's specifications. In many cases adjustments to the equipment or system will need to be made by the contractor to meet this level of performance. As HVAC installers increase the regularity of this type of evaluation on new or existing furnaces, they will subsequently increase their focus on the equipment's installed performance.

The objective of this project is to explore the energy savings potential of maximizing furnace and distribution system performance by adjusting operating, installation, and distribution conditions. Furnaces in existing homes were evaluated by home energy professionals and specially trained HVAC SAVE contractors. This evaluation consisted of measuring airflows, static pressures, and temperatures across the system to determine how well the furnace was performing as compared to the manufacturer specifications. If it was determined that the furnace was underperforming, possible causes were identified from the data so that repairs or adjustments could be made to maximize the performance. Through incentive programs like this one, proper furnace installation techniques and duct system upgrades that produce optimal system performance are rewarded and equipment retrofits are able to achieve their full energy savings potential.

2 Experimental Methods

This project determines the efficacy of the HVAC SAVE program through examining the performance of HVAC systems in-situ both before and after tuning and distribution system changes are made. The project consists of two parts:

1. Baseline system evaluation results from a sample of existing homes before any repairs or adjustments are made. These data are used to estimate energy savings if the heating system was operating at its full potential.
2. In-depth study on data from a smaller sample of homes that have completed an initial evaluation, system modifications (tuning or replacement), and a post-work evaluation. Of this dataset, three homes are selected for in-depth analysis to compare the estimated energy savings pre- and post-testing.

All in-home evaluations were completed by home energy professionals or specially trained HVAC contractors following performance testing methods taught in the HVAC SAVE training. A detailed description follows.

2.1 Research Questions

This project will answer the following research questions:

- What is the achievable improvement in HVAC system operating efficiency from common modifications and quality installation of new equipment?
- What is the current typical installed HVAC system operating efficiency, as defined by the capacity of conditioned air reaching building occupants?

2.2 In-Home Evaluation Procedures

A key component of the performance testing procedures is the “test-in,” an evaluation of the actual installed performance of the furnace and HVAC system prior to any improvement work being conducted. Information collected as part of this initial evaluation, with instrumentation accuracies, includes:

- Furnace nameplate data and general housing characteristics, including conditioned floor area and location of supply and return ducts.
- Airflow at the equipment by one of three methods (below). The first two methods are preferred, as pressure matching is prone to errors.
    - Traversing using a hot wire anemometer with a stated instrument accuracy of ± 6 fpm (± 5% of the reading)
    - Using a flow grid with a manufacturers stated accuracy of ± 7% of the reading
    - Matching static pressure drops across the equipment with OEM values.
- Fuel input rate by clocking the gas meter (timing the gas flow rate).

- Measured external static pressure (ESP) using a static pressure probe with at stated instrumentation accuracy of ± 2% of the reading.
- Temperature rise across the equipment and at the supply and returns grilles with an instrumentation accuracy of ± 0.5°F.

A complete list of information collected during the test-in process can be seen in Appendix B. All of the measurements listed above were taken when the furnace was warmed up and running steadily. Ensuring the furnace is warmed up is important because it allows for the calculation of steady-state efficiency. This information is compared with the equipment rated values and manufacturer nameplate to determine if the equipment is operating at optimal levels.

The metric used to determine energy savings potential is conversion efficiency:

$$\frac{\text{Energy out (Btu delivered by the furnace to the circulating air)}}{\text{Energy in (Btu content of the natural gas*AFUE)}} \quad (1)$$

Energy out = CFM *Temperature Rise *1.08 (specific heat value)

Energy in = Measured gas flow rate * gas heating value * AFUE

In order to quantify the amount of energy entering the distribution system for each tested furnace, temperature rise and airflow across the heat exchanger are recorded while the furnace is in operation. The amount of energy that should be delivered by the furnace is determined by taking the measured gas flow rate (i.e., clocking the gas meter), multiplying by the local gas heating value, and multiplying by the AFUE. The amount of energy added to the airflow is calculated by measuring the temperature of the air entering and leaving the furnace and airflow rate of air leaving the furnace. By comparing these two values (the conversion efficiency) the research team can determine what percentage of the theoretical maximum available energy is actually entering the distribution system.

Following HVAC SAVE protocols, if a furnace is delivering less than 90% of the post-AFUE energy available based on the fuel input (accounting for AFUE), then repairs or adjustments to the system are deemed appropriate. Other measurements taken during the test-in are used to identify possible improvement opportunities. The first such measurement is the airflow across the heat exchanger. If the airflow is lower than the manufacturer's recommendation, then an adjustment to the blower motor speed is deemed appropriate. This simple step is often overlooked during installation. Once the setting has been confirmed or adjusted, static pressure measurements are taken and compared with the rating of the equipment. If this value is higher than 125% of the maximum ESP rating recommended by the manufacturer on the nameplate, it is considered to be above the desired range. Furnaces that are operating above this range are evaluated further by examining pressure drops across individual components in the system. Each section or component is allotted a specific portion of the total ESP. Allocation of external static pressure is determined using a standardized pressure budget table that takes into account fan type and coil placement. Exact proportions of the ESP allocated to the coil, filter, supply, and return are dependent on type of furnace. The exact values provide a guide for the contractor to determine which locations in the system are restricting airflow.

Once the airflow across the heat exchanger has been properly adjusted, the fuel input rate and temperature rise across the heat exchanger are examined. Furnaces with a firing rate not within ± 5% of the nameplate rating are considered over- or under-fired and adjustments are required. After the fuel input rate is correctly set combustion tuning can be conducted using a handheld combustion analyzer. When all of these procedures are complete, the furnace is retested to determine if it is operating at or close to its rated capacity.

Airflow at the equipment was measured using one of three methods: traversing using a hot wire anemometer, flow grid, or matching static pressure drops across the equipment with original equipment manufacturer values. Procedures for measuring airflow using the flow grid are described in ANSI/ASHRAE 152-2004, while the traverse procedures are described in ANSI/ASHRAE 111-2008. While ideally a single method of measurement would have been used, the variability of installations in the field did not allow for this. The preferred method of measurement was either the hot wire anemometer or the flow plate. In instances where neither of the two preferred measurement methods was appropriate, the static pressure drop matching was used. This method is less accurate and is prone to potential errors.

2.3 Data Collection

The sample set for this project came from a database of homes that have been evaluated through the test-in process as a part of the HVAC SAVE program in Iowa. This program began in November 2010 with limited program participation and thus the sample set was modestly sized. Initially this set contained 102 homes but the research team eliminated all but 48 homes as only these met the selection criteria of having received a complete test-in of a forced-air natural gas furnace. The team removed 22 homes that had data on central air conditioners only and 10 that were geothermal heat pumps, air source heat pumps, or strip heat. Four were removed for being commercial buildings and the remaining 18 were removed due to having not completed the entire test-in procedure.

The 48 Iowa homes that were evaluated as part of this project had average conditioned floor space of 2,645 ft^2, ranging from 780 ft^2 to 4,760 ft^2. Supply and return ducts in these homes were located completely (100%) in conditioned space in all but four of the homes. Of the furnaces tested, 33 were condensing (AFUE 90%–95%). The minimum recorded AFUE was 78%. The furnaces ranged in age from brand new to greater than 15 years old and had an average rated input of 81,781 Btu/h. Table 1 illustrates furnace age. Figure 2 shows the furnace input capacity sorted from smallest to largest.

Table 1. Age of Furnaces in Test Homes

Furnace Age	Number of Furnaces
New	4
0–5 Years Old	3
5–10 Years Old	17
10–15 Years Old	6
> 15 Years Old	18

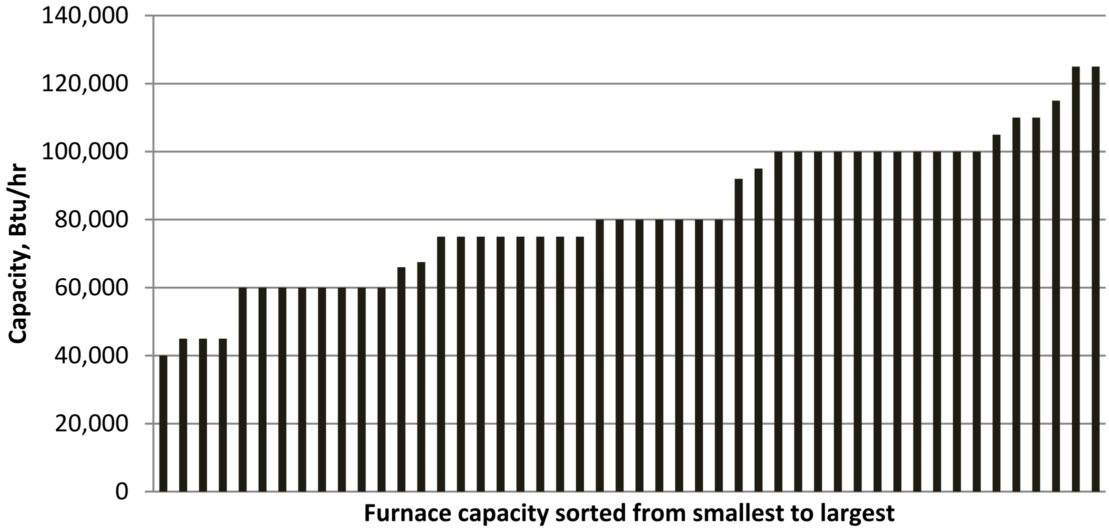

Figure 2. Furnace input capacity

In the second part of the project, the team studied 10 homes that had completed test-in, system modifications, and test-out procedures. The objective of this work is to determine the energy savings that could actually be achieved from the HVAC SAVE procedures. Three of the 10 homes were chosen for in-depth case studies, including utility bill analysis. "Test-out" follows the same procedures as the "test-in" (see Section 3). Comparing test-in and test-out allows for performance improvements resulting from the repair or modification to be clearly measured. Similar to the case study homes, the remaining seven homes analyzed in this part of the study have undergone HVAC equipment replacement and system tune-ups. All seven of these homes received a test-in before the work was completed and a test-out after the work was completed. These seven additional homes will assist in investigating the hypothesis that many furnaces are installed outside their recommended operating settings and can benefit from system tune-ups.

3 Results

3.1 Field Data Summary Statistics

In the first part of this study, field data were evaluated from 48 existing homes with natural gas furnaces located in central Iowa. The data were collected during test-in evaluations completed by home energy professionals who have several years of experience conducting this type of testing.

Equipment static pressures were measured with a static pressure probe using the methods described in ASHRAE Standard 111-2008. Figure 3 shows the recommended airflow values sorted from smallest to largest with each home's corresponding recorded airflow. Figure 4 shows the distribution of measured ESP for the 47 homes that had blower motors rated at 0.5 i.w.c. (one home was removed from this set as its blower motor was rated at 0.2 i.w.c.; this furnace had a measured ESP of 0.55 i.w.c.). Recorded airflows ranged from 540 CFM to 1,877 CFM, with the recommended levels ranging from 520 CFM to 1,650 CFM (ASHRAE 2008).

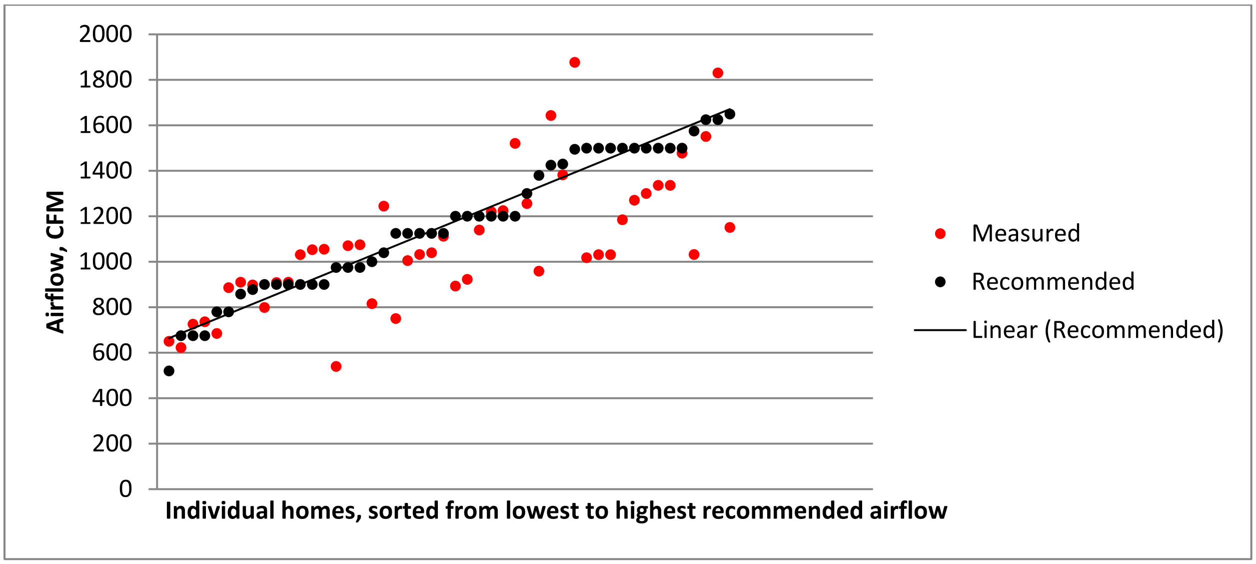

Figure 3. Recommended and measured airflows by individual home

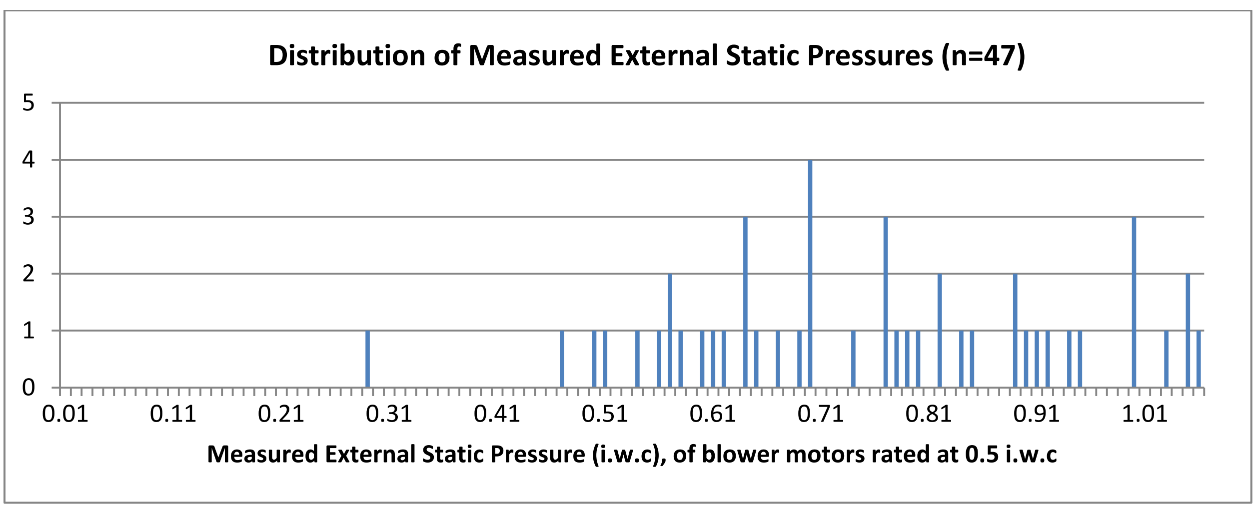

Figure 4. Measured ESP (i.w.c) of blower motors rated at 0.5 i.w.c.

Pressure drops across individual components were also measured to identify where restrictions in the system exist. As shown in Figure 5, the four locations where pressure drops were measured are the coil, filter, supply duct, and return duct. Individual component static pressure measurements are important because they shed light on how measured static pressure compares with the pressure budget. The average ESP values for external coil, filter, supply ducts, and return ducts are 40%, 20%–30%, and 20%–15%, respectively.

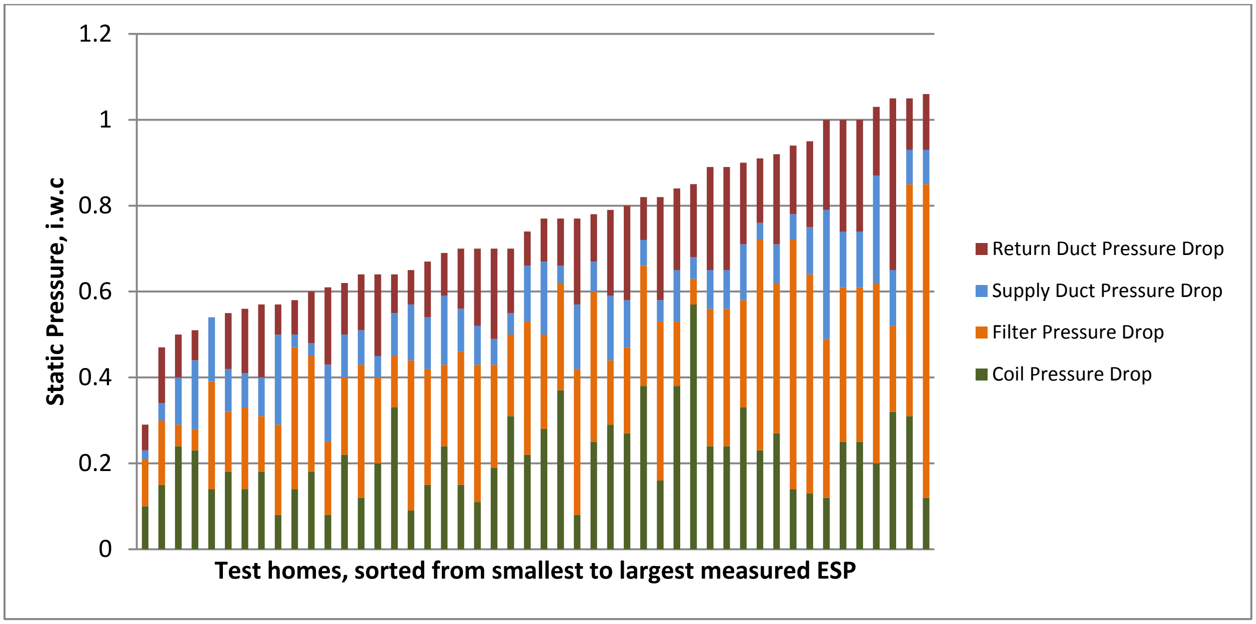

Figure 5. Recorded static pressure drop, by component

By clocking the gas meter on these sample homes, the team was able determine the fuel input to the furnace. Figure 6 shows the actual measured input to the furnace compared with the rated input. Measured inputs on the 48 sample homes ranged from 37,037 Btu/h up to 163,636 Btu/h. Combustion analysis testing was also conducted on 36 of the 48 homes. Flue temperatures ranged from 314°F to 519°F on induced draft furnaces and 91°F to 138°F on condensing furnaces. Equipment temperature (the temperature of the air leaving the furnace) and percentage of oxygen were also recorded on these homes. Results of the flue gas testing are shown in Figure 7. The two furnaces that have oxygen percentage readings in the 4% range also had high carbon monoxide readings.

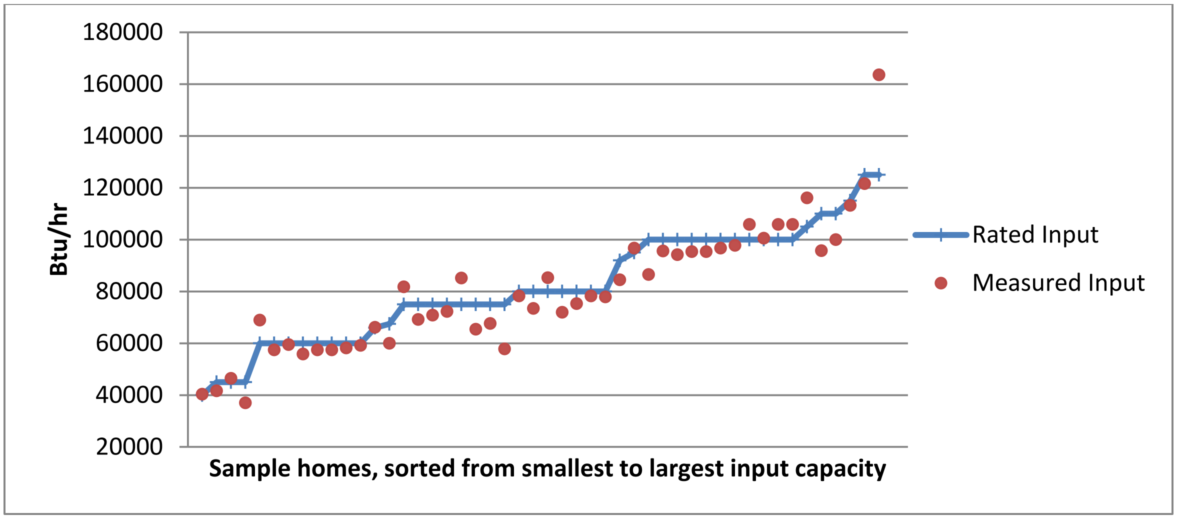

Figure 6. Btu/h input to furnace

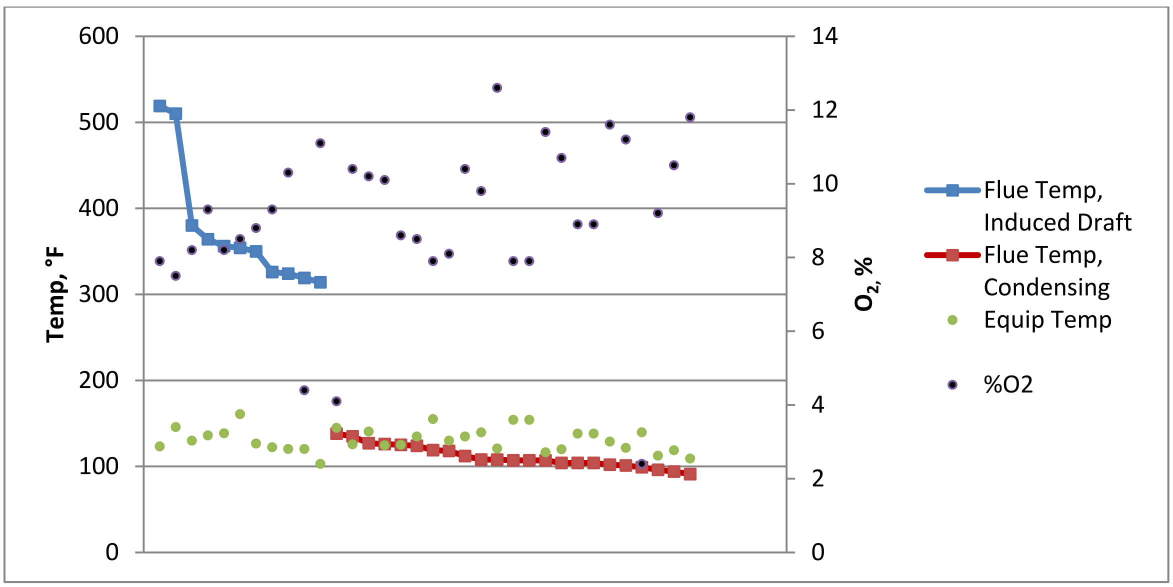

Figure 7. Results of flue gas testing (Condensing and Induced draft furnaces)

Figure 8, below, shows the comparison between label AFUE and test-in steady-state efficiency. Note that steady-state efficiency varies both above and below the AFUE; this is likely due to natural variations in the observed operating condition.

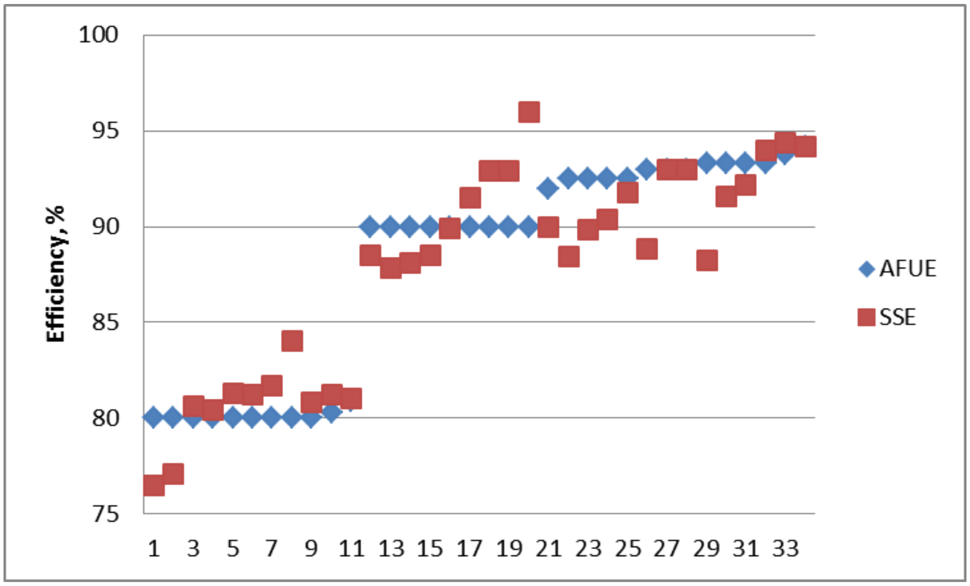

Figure 8. Label AFUE versus test-in steady state efficiency

3.2 Ten Test Homes

For the second part of this experiment, test-in and test-out data for 10 homes have been analyzed. Four of the 10 homes have undergone equipment replacement and system tune-ups and the remaining six have undergone system tune-ups only. Two of the three in-depth case studies have undergone equipment replacement and one test home had the tune-up only. The results presented here shed light on how directed system-level improvements can improve the efficiency of residential heating and cooling systems.

3.2.1 Three In-Depth Case Study Homes

Test home #1, shown in Figure 9, is located in Johnston, Iowa. Built in 1993 it has 2,414 ft^2 of conditioned floor space and 100% of the supply and return ducts are in conditioned space. This home contained a 100,000 Btu induced draft furnace rated at 80% AFUE. At test-in the recorded airflow was 1,016 CFM versus the recommended level of 1,300 CFM. Measured ESP was 0.88 i.w.c with the blower motor having a rating of 0.5 i.w.c. The following repairs or adjustments were made to test home #1:

- Furnace replaced, reducing capacity from 100,000 Btu 80% AFUE to 66,000 Btu 95% AFUE
- Combustion tuning conducted on new furnace once airflow was set correctly
- Ductwork leaks repaired and entire duct system sealed using the Aeroseal process.

Figure 9. Test home #1

Table 2. Test Home #1

	Pre-Retrofit	Post-Retrofit
AFUE, %	80	95
Rated Input, Btu	100,000	66,000
Total ESP, i.w.c.	0.88	0.4
Target ESP (Nameplate), i.w.c.	0.5	0.8
Temperature Rise Across the Equipment, °F	45.1	49.4
Supply Register Average Temperature, °F	107.3	103.7
Required Fan Airflow, CFM	1300	990
Recorded Fan Airflow, CFM	1016	1089

These repairs were completed in February 2011 and a test-out of the system was done shortly after completion of the work. The new equipment is a 66,000 Btu 95 AFUE condensing furnace, airflow across the equipment was measured at 1,089 CFM, slightly above the recommended level of 990 CFM. After the ducts were repaired and sealed, the new furnace had an ESP of 0.4 i.w.c., well below its rated 0.8 i.w.c. Figure 10 below shows the natural gas consumption of the home pre- and post-retrofit. While the most recent winter was warmer than the previous two, based on heating degree days (HDDs), the natural gas consumption post-retrofit over the four billing periods ending in October, November, December, and January (2011–2012) was 32% less than the same four-month period (2010–2011) when the summer base load is factored out. The HDDs over the same four-month period are 16% fewer post-retrofit than pre-retrofit. When adjusted for HDD differences, the savings was approximately 16%. Data were normalized for weather using ENERGY STAR® Portfolio Manager's Methodology for Accounting for Weather procedure. Further data collection, especially over a typical winter with temperatures close to design conditions, is required to assess the energy savings from this upgrade.

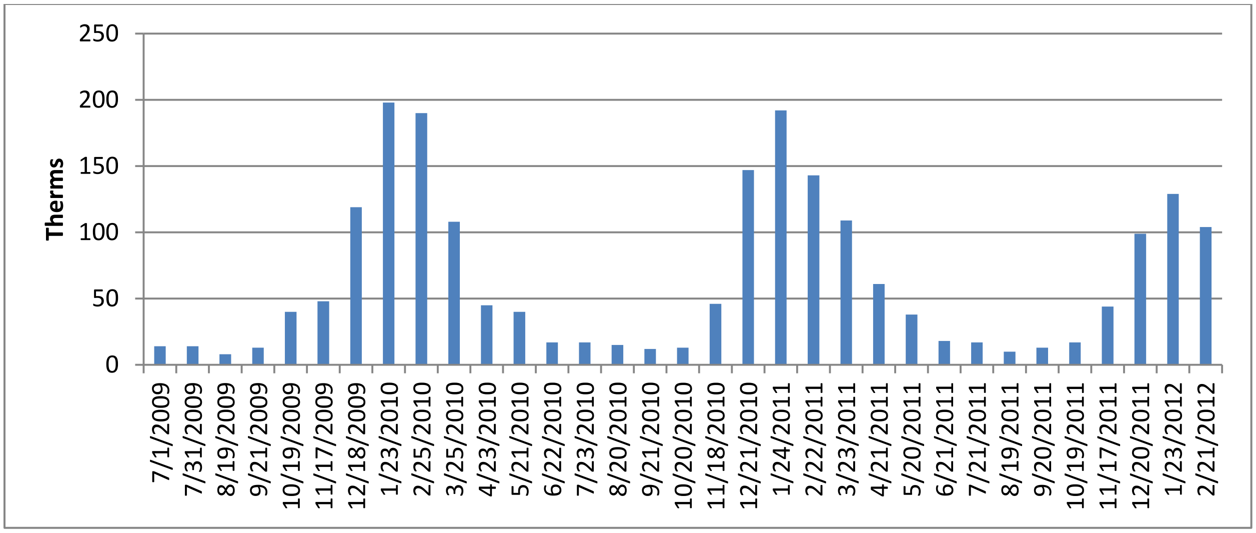

Figure 10. Test home #1, natural gas usage pre- and post-retrofit

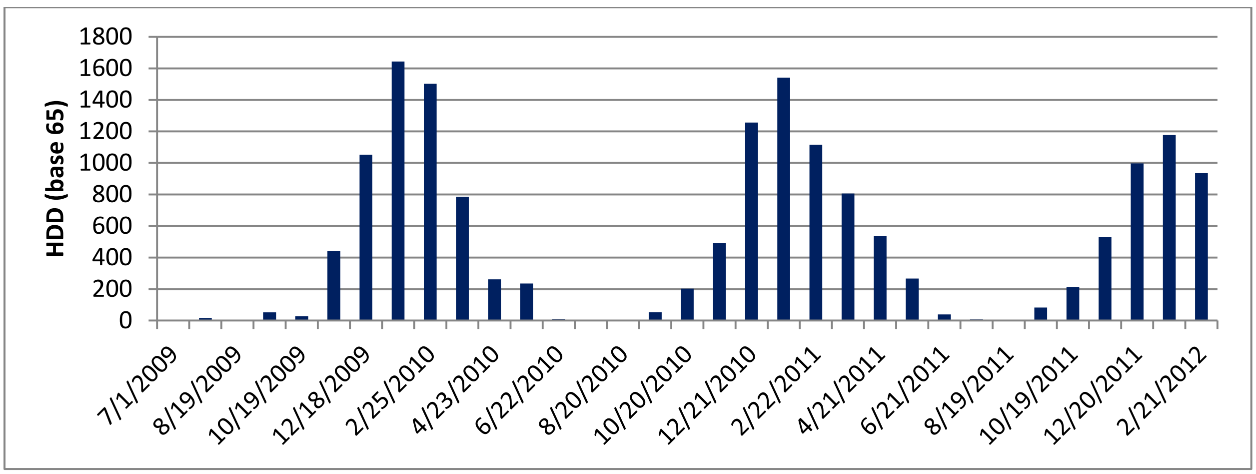

Figure 11. Test home #1, HDD (base 65) per month

Test home #2 is located in West Des Moines, Iowa. It was constructed in 1986 and has 2,698 ft^2 of conditioned space and 100% of the supply and return ducts are in conditioned space. The home contains a 100,000 Btu condensing furnace with airflow at the equipment during initial testing of 988 CFM, below the required 1,500 CFM. The measured ESP was 0.29 i.w.c. versus the blower motor rating of 0.5 i.w.c. Based on the conditions found in the home the following repairs or adjustments were made:

- Ductwork repaired; returns that were found to be communicating with the outdoors sealed
- Additional returns added
- Fan speed increased
- Entire duct system sealed using the Aeroseal process.

Figure 12. Test home #2

Table 3. Test Home #2

	Pre-Retrofit	Post-Retrofit
AFUE	93	93
Rated Input, Btu	100,000	100,000
Total ESP, i.w.c.	0.29	0.38
Target ESP (Nameplate) i.w.c.	0.5	0.5
Temperature Rise Across the Equipment, °F	57	59
Supply Register Average Temperature, °F	138	144
Required Fan Airflow, CFM	1500	1500
Recorded Fan Airflow, CFM	988	1238

The modifications on test home #2 were completed in December 2011. The test-out showed an increased airflow to 1,238 CFM, which raised the ESP to 0.38 i.w.c. The original equipment was not replaced as part of this job.

Pre- and post-retrofit utilities bills were gathered to examine the energy saving from the repairs made. Figure 13 shows the natural gas consumption of the home from September 2010 through February 2012. The last two columns of the graph show post-retrofit consumption. Since this installation was so recent, energy savings from these repairs is difficult to quantify. The natural gas usage from January and February 2012 is 33% less than the same period in 2011, while the HDDs over the same periods are 27% less. Since the most recent winter was milder (based on HDD) than the same period during 2010–2011, short-term year-over-year energy savings are difficult to predict. Original equipment remained in use post-retrofit; therefore, this home is a good candidate for longer term monitoring. The research team will continue to collect utility billing data on this home over the course of the next year to quantify the energy savings from these system repairs.

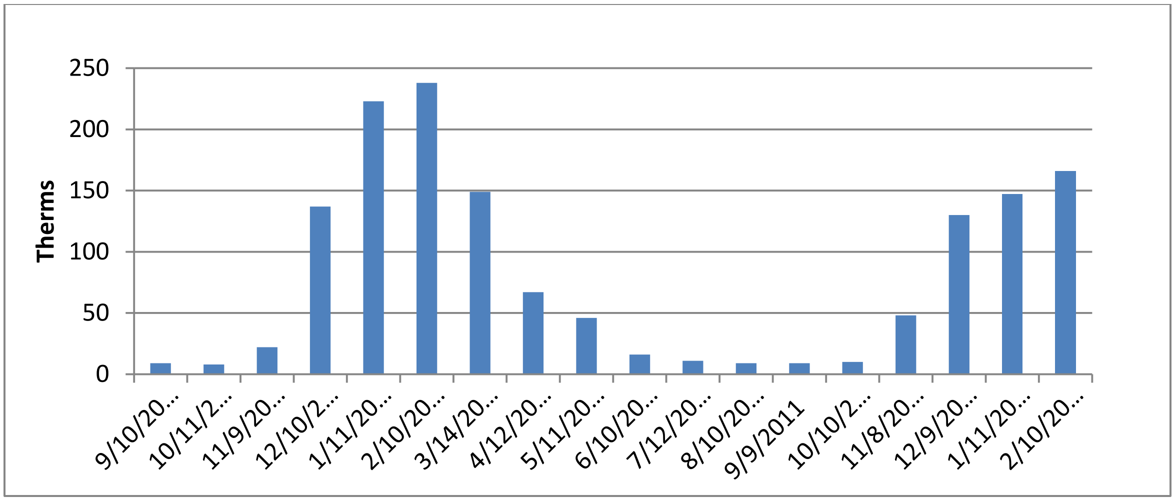

Figure 13. Test home #2, natural gas usage per month (therms)

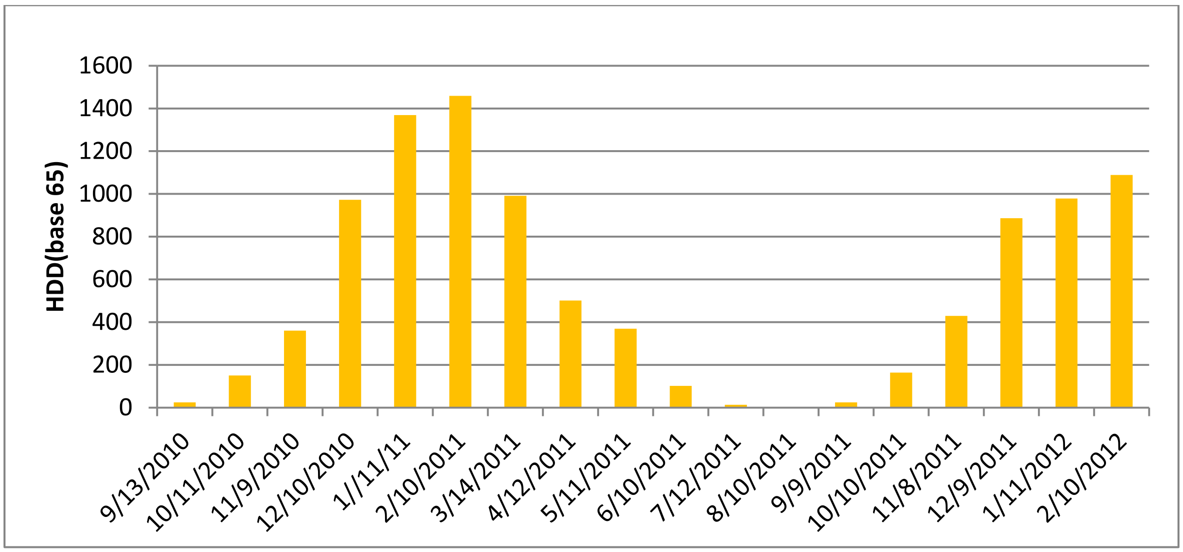

Figure 14. Test home #2, HDD (base 65), per month

Figure 15 shows test home #3, located in Des Moines, Iowa. It was built in 1963 and has 1,520 ft^2 of conditioned floor space. The home contained a 100,000 Btu/h furnace, with a measured airflow at the equipment of 1,425 CFM. The temperature rise across the equipment was 56 °F with an average supply register temperature of 127.9°F. ESP was 0.83 i.w.c., with the blower motor rated at 0.5 i.w.c. The following repairs or adjustments were made to test home #3:

- 100,000 Btu furnace replaced by a 66,000 Btu, 97% AFUE condensing furnace
- Duct system repaired and sealed.

Figure 15. Test home #3

Table 4. Test Home #3

	Pre-Retrofit	Post-Retrofit
AFUE	92	97
Rated Input, Btu	100,000	66,000
Total ESP, i.w.c.	0.83	0.6
Target ESP (Nameplate), i.w.c.	0.5	0.8
Temperature Rise Across the Equipment, °F	56	56
Supply Register Average Temperature, °F	127.9	126.3
Required Fan Airflow, CFM	1,500	990
Recorded Fan Airflow, CFM	1,425	875

Repairs were completed on test home #3 in December 2011. "Test-out" data on the new condensing furnace showed measured equipment airflow of 875 CFM and an ESP of 0.6 i.w.c. The temperature rise and supply register temperatures were similar to the pre-retrofit conditions.

Since this repair was completed recently, natural gas utility bills pre- and post-modification do not provide significant insight into whether any energy savings were achieved. Figure 16 and Figure 17 show the billing and HDD data. The billing cycles ending in January and February 2012 show 21% less natural gas use than the same two-month period in 2011 when summer natural gas usage is factored out. During this same two-month period, the number of HDDs was 20% fewer this year versus the previous year. Since the most recent winter was milder (based on HDD) than the same period during 2010–2011, short-term year-over-year energy savings are difficult to predict.

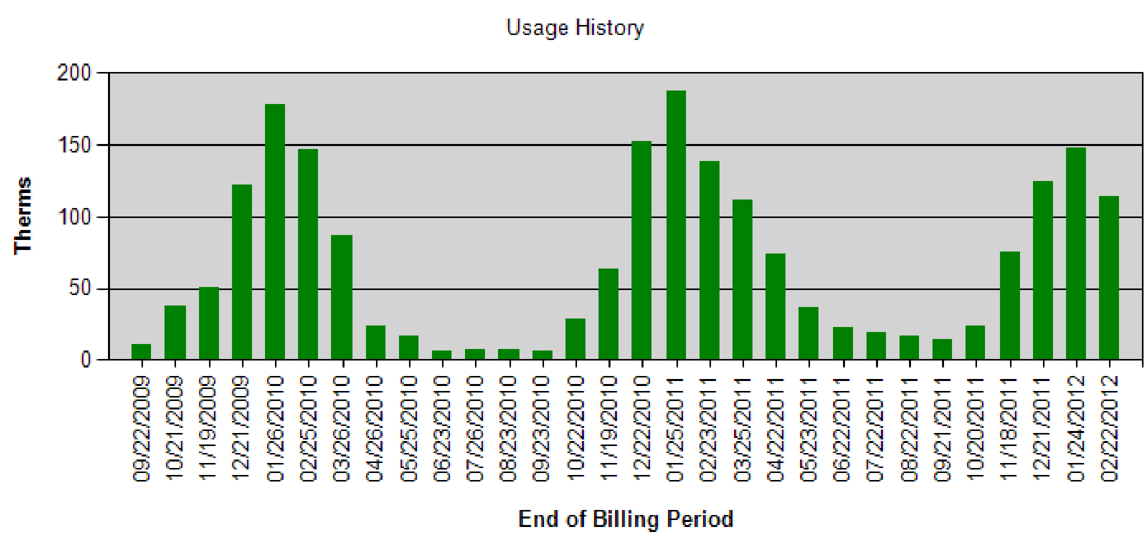

Figure 16. Test home #3, natural gas usage per month (therms)

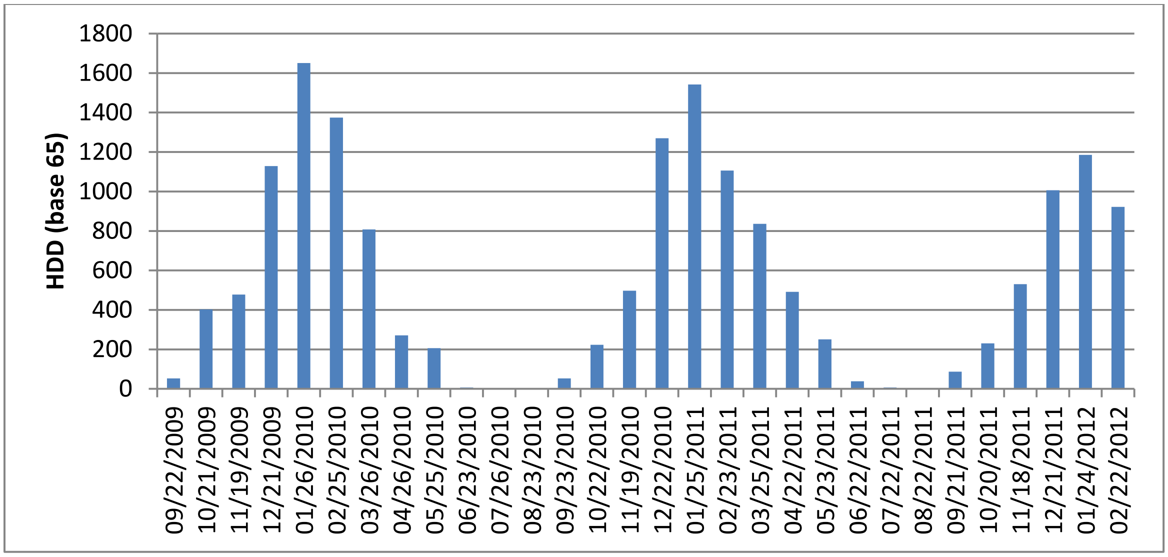

Figure 17. Test home #3, HDD (base 65), per month

3.2.2 Seven Supporting Test Homes

An additional seven test homes were studied to determine if furnaces installed outside their optimal operating settings and can benefit from system tune-ups. The seven homes being reported here have undergone HVAC SAVE system repairs, system adjustments, and equipment replacements. Similar to the three case study homes, test homes #4 through #10 (TH-4 to TH-10) were located throughout Iowa and the work was performed by HVAC SAVE certified contractors. The HVAC diagnostic data depicted in this section is identical to the three case-study homes except utility bill analysis is not included (Appendix A). Analysis of these seven homes shows significant improvements in HVAC equipment and system efficiency. Table 5 lists the difference (after tune-up minus before tune-up) before and after either equipment replacement or system tune-up.

Four test homes have undergone equipment replacement and six homes have undergone system tune-ups without replacement (Table 5). All six homes that underwent tune-ups have shown noticeable improvements in conversion efficiency and overall system efficiency. Measured conversion efficiency improvement, for system tune-ups only, ranged from 7% to 23% and system efficiency improvement ranged between 1 percent and 23 percent (Table 5). Eight of the 10 total test homes showed an increase in equipment temperature rise and in seven out of 10 test homes there was an increase in system temperature rise (Table 5). Changes in equipment and system temperature rise were 0°–13°F and 2.1°–19.5°F, respectively (Table 5). Specifically, the six homes that underwent system tune-ups only showed increases in conversion efficiency, system efficiency, equipment temperature rise (except TH-10), and system temperature rise (Table 5). Table 6 lists the average changes between the pre- and post-test in data.

Table 5. HVAC System Replacement and Tune-Up Diagnostic Data (Shaded Columns Underwent Equipment Replacement): Post-Tune-Up Minus Pre-Tune-Up Diagnostic Data

		TH-1	TH-2	TH-3	TH-4	TH-5	TH-6	TH-7	TH-8	TH-9	TH-10
Temp rise across the equip.	F	4.3	2	2	2.1	-28.7	14.9	1	13	13	0
System temp Rise	F	0	6.1	2.1	-4.7	-21.5	11	12	19.5	17.9	12.9
Supply reg ave temp	F	0	6	-1.6	3	-13	14.6	12	20	17.4	14.4
Required fan airflow	CFM	-310	0	-510	-105	-100	0	0	0	0	0
Recorded fan airflow	CFM	73	0	-550	-500	229	23	1	0	0	219
Conversion efficiency	%	51%	14%	10%	16%	23%	1%	23%	10%	22%	13%
System efficiency	%	26%	18%	5%	-21%	7%	6%	28%	22%	26%	17%

Table 6. HVAC System Replacement and Tune-Up Diagnostic Data: Average Differences

		Equipment replacement	Tune-up
Temp rise across the equip.	F	-5.08	7.32
System temp Rise	F	-6.03	13.23
Supply reg ave temp	F	-2.90	14.07
Required fan airflow	CFM	-256.25	0
Recorded fan airflow	CFM	-187	40.5
Conversion efficiency	%	25%	14%
System efficiency	%	4%	20%

2.3.3 Test Home HVAC System Upgrades

Six out of the 10 homes analyzed in this study underwent system tune-ups only and the remaining four underwent equipment replacements. The four homes that underwent equipment replacement installed new furnaces with reduced rated output capacity and improved AFUE (Table 7). Along with a proper installation, these four homes were also able to appropriately size their furnaces to meet their heating demands. The system tune-ups largely involved the improved delivery of conditioned air. System tune-up information for each test home is listed in Table 7. Tune-up measures are home specific because they are largely dependent on the pre-existing distribution system conditions. For instance, high static pressure in the return system would lead to an improvement or addition to the return system ducts. Although the actual tune-up components vary widely, the end result of the tune-up is an increase in both the equipment and system efficiency.

Table 7. Test Home Repairs and Adjustments (Replacements Shaded)

Test home # 1	Test home # 2	Test home # 3	Test home # 4	Test home # 5
Johnston, IA	West Des Moines, IA	Vernon, IA 52314	Mount Vernon, IA	Mount Vernon, IA
Furnace replaced, reducing capacity from 100,000 Btu 80% AFUE to 66,000 Btu 95% AFUE, Combustion testing conducted, Ductwork repaired and sealed	Duct work repaired, Additional return ducts added, Fan speed increased, Ducts sealed	Furnace replaced, reducing capacity from 100,000 Btu to 66,000 Btu 97% AFUE, Duct system repaired and sealed	Furnace replaced, reducing capacity from 60,000 Btu 71% AFUE to 45,000 Btu 93% AFUE	Furnace replaced, reducing capacity from 100,000 Btu 80% AFUE to 54,000 Btu 89% AFUE

Test home # 6	Test home # 7	Test home # 8	Test home # 9	Test home # 10
Lisbon, IA	Council Bluffs, IA 1	Council Bluffs, IA 2	Council Bluffs, IA 3	Council Bluffs, IA 4
Increased airflow, Insulated supply ducts and adding more	Supply duct system repaired filter replacement, Coil cleaned, Supply ducts added	Increased delivered Btu(s) to match equipment capacity	Increased delivered Btu(s) to match equipment capacity	Increased delivered Btu(s) to match equipment capacity, Return ducts added

4 Discussion

For the set of 48 homes evaluated in the first part of this project, the average calculated conversion efficiency, as defined in Equation 1 in Section 3, was 81%. Based on the authors' previous experience, a conversion efficiency of 90% or better is easily achievable and can be reached by taking simple, low-cost actions such as properly setting fan speed or tuning the combustion. Of the 48 sample homes, only eight (17%) were considered to be operating with a conversion efficiency of 90% or better at test-in. Figure 18 shows the distribution of calculated conversion efficiencies.

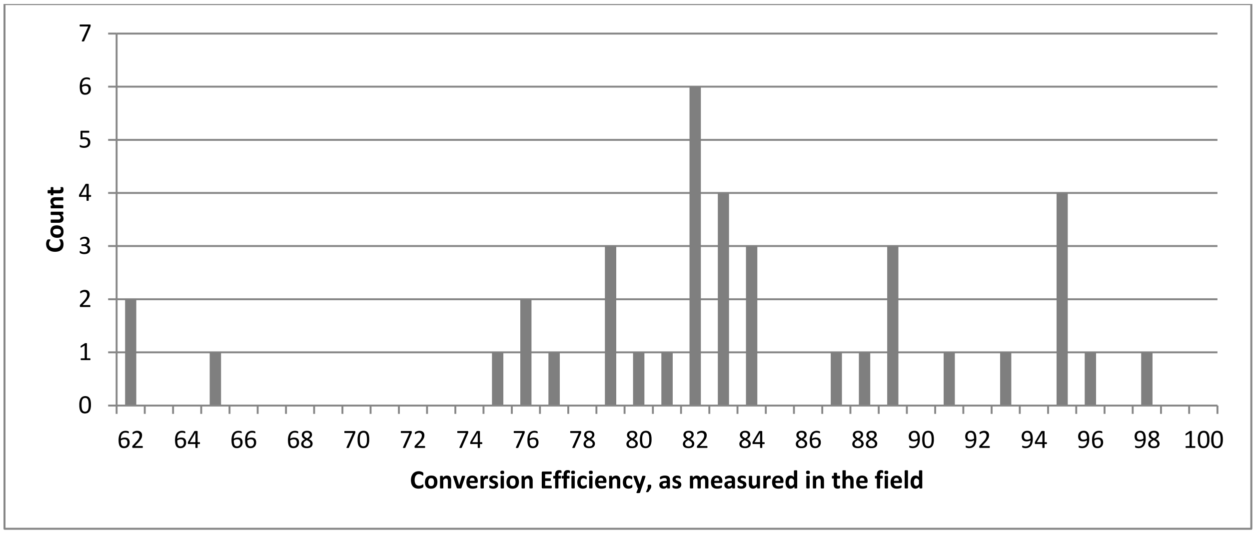

Figure 18. Distribution of calculated conversion efficiencies

Achieving close to 100% conversion efficiency is not out of reach, but may require making costly repairs or adjustments to the equipment and distribution system. Adjusting a system to operate at 90% conversion efficiency is a more realistic objective. If the average efficiency of the equipment in the homes were raised to this meet this objective, there would be an average of 9% reduction in energy input. When factoring in the average space heating energy consumption per household for the Midwest, the historical average heating load (36.85 kBtu/ft^2/yr), the average AFUE (88%) and the average conditioned floor space (2,644 ft^2) of the 48 sample homes, this would result in a savings of 13.7 MBtu (site) or 9% of the total annual household heating energy consumption. The estimated source annual energy savings based on these assumptions and a conversion factor of 1.092 (Uneo and Straube 2010) is 14.96 MBtu. The average conditioned floor space in our sample 48 homes was significantly larger than the average conditioned floor space for the region based on the Energy Information Administration's Residential Energy Consumption Survey (EIA 2009). The average floor space for the West North Central Region, which contains Iowa, was 1,930 ft^2. When the estimated energy savings is calculated using this value instead of the floor space from the sample homes, the estimated energy saving are 10 MBtu (site) and 10.9 MBtu (source).

In order to achieve these energy savings in the field, many of the homes tested through this project would need repairs or adjustments made to the system. The first step in most cases should be to evaluate airflow at the heat exchanger and verify that the equipment is achieving the desired level. The airflow at the heat exchanger measured in these homes was outside of the recommended range (100% ± 15%) in 20 (42%) of the 48 homes, as shown in Figure 19. This range was chosen based on recommendations published in ANSI/ACCA 5 QI-2010. For airflows outside of this range, fan speeds should be verified and static pressures across system components should be evaluated to locate restrictive locations.

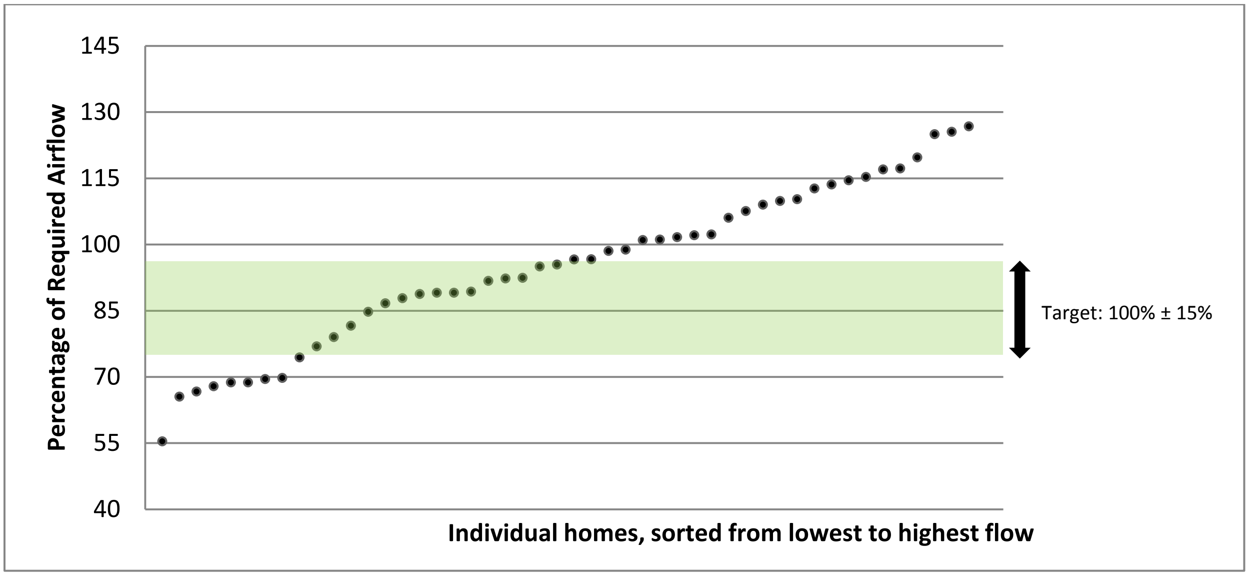

Figure 19. Percentage of required airflow across heat exchanger as measured in the home

Of the 48 homes in the sample set, 32 (73%) had an ESP higher than 125% of that recommended by the manufacturer, as seen in Figure 20. This maximum value was chosen based on ANSI/ACCA 5 QI-2010. It should be noted that the outlier on the far right side of Figure 20 is the single home in our sample set that had a blower motor that was rated at 0.2 i.w.c. When tested the ESP on this system came it at 0.55 i.w.c, or 275% of its rated static pressure.

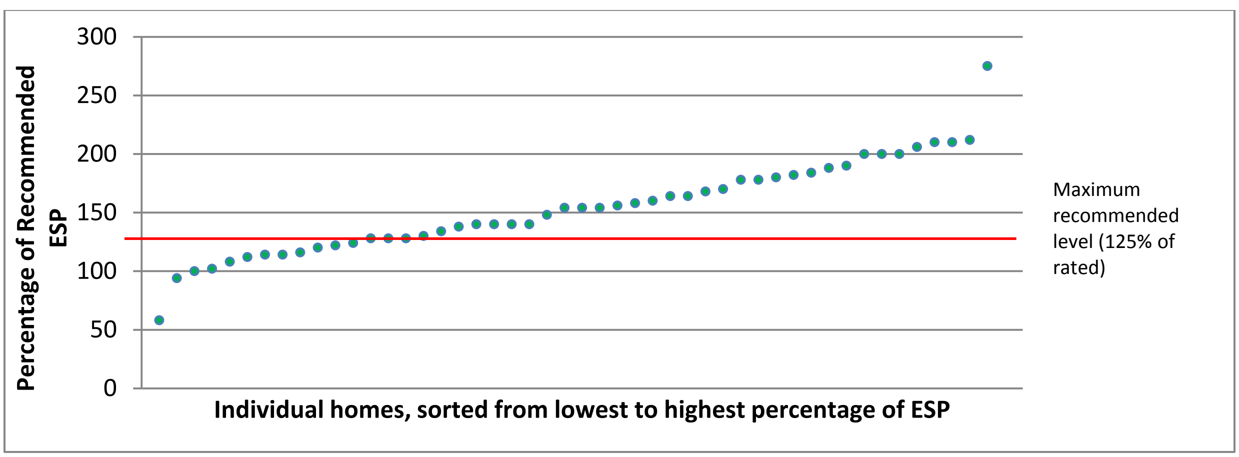

Figure 20. Percentage of required airflow across heat exchanger as measured in the home

One method to identify where airflow restrictions in the system exist is to examine the pressure drops across individual components in the system. As described in Section 3, each section or component was allotted a portion of the total ESP: 40% for the coil, 20% each for the filter, supply, and return. Using these values as a guide, the project team examined the set of sample homes to conclude which locations in the system were restricting airflow.

Based on these guidelines, and as shown in Figure 21, 43 of the homes were identified as having a restrictive filter and 31 were identified as having a restrictive return. Since both of these locations are on the return side of the furnace, performing system repairs targeted at one or both locations could prove to be cost effective. It should be noted that each home can have more than one restrictive location.

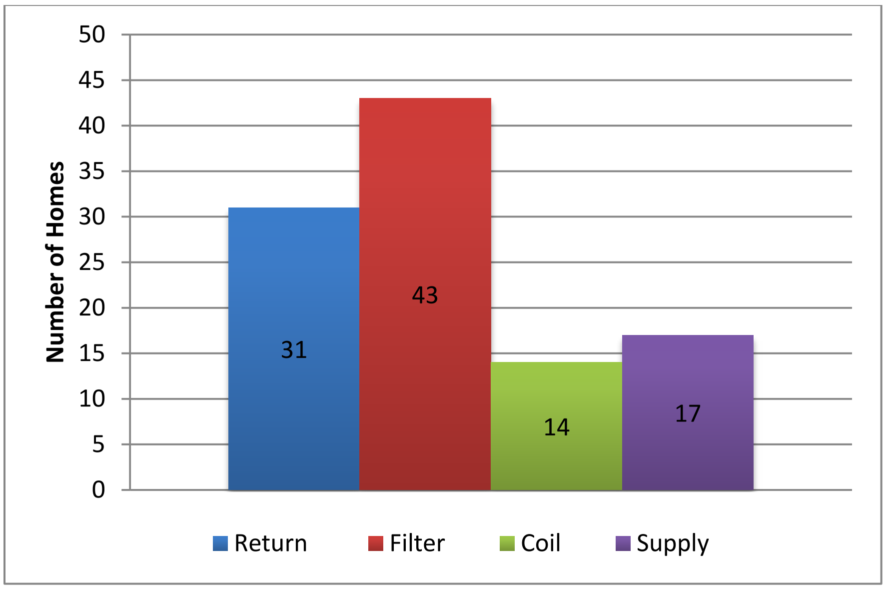

Figure 21. ESP restriction, by location

Once the airflow has been corrected, the firing rate can be checked to see how it compares to the rated input. ANSI/ACCA 5 QI-2010 recommends that the firing rate should be within ± 5% of equipment nameplate input. Using this as a guide, 17 (25%) of the 48 homes were under-fired while 9 (19%) were over-fired (Figure 22).

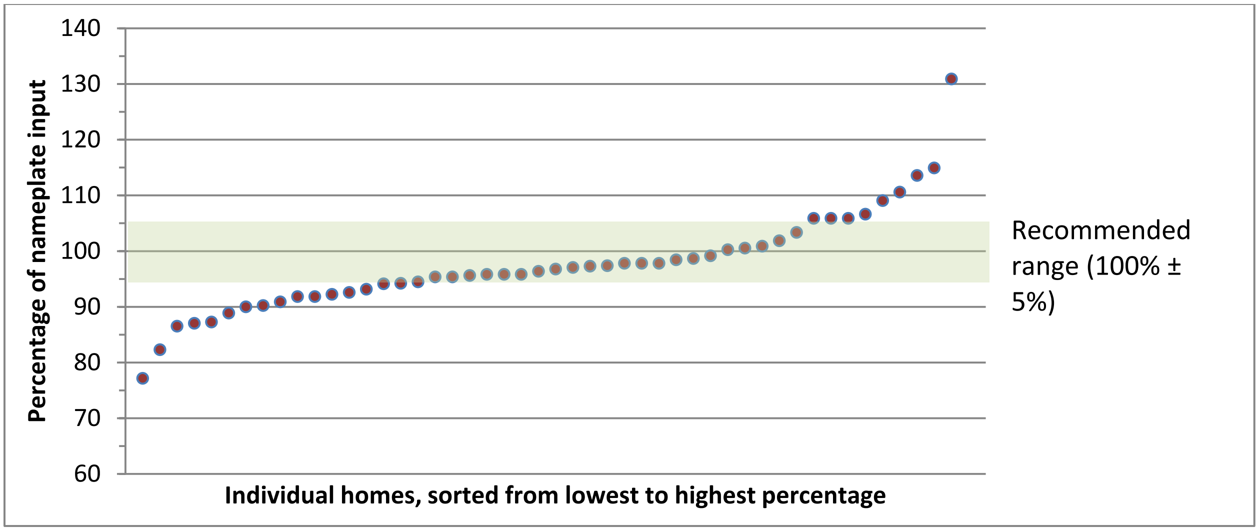

Figure 22. Measured fire rate as a percentage of nameplate input

Based on the 48 sample homes, it can be seen that the furnaces looked at in this study are not operating under conditions recommended by the manufacturer or best practice installation standards. Further investigation is needed to quantify the impact of these adverse conditions on performance. PARR plans to build on the data presented in this report and conduct laboratory testing of vintage furnaces under conditions as found in the field to see how they affect common performance metrics, such as AFUE.

While the additional long-term energy use data need to be collected on the three sample homes in order to provide a more accurate prediction of energy savings, the initial results on two of the three homes suggest that the repairs or replacements did indeed save energy, while the third home had an effective energy savings of 1% over the first two months after the repairs were completed. Home #2 provides the most promise for future results, as the existing equipment remained in place after the repairs and system adjustments took place. On this home adding an additional return, increasing the fan speed, and sealing the distribution system show an effective energy savings of 6% over the first two months after the repairs were completed. Home #1 showed an effective energy savings of 16% over the first four months after the repairs were completed. Savings on this home as a result of system repairs will be difficult to quantify, as the equipment was also replaced as part of this modification. The original 80% AFUE furnace on this home was replaced with a 95% AFUE model, so a portion of this energy savings can be attributed to the increase in conversion efficiency.

The 10 homes analyzed in third part of this study are important, because they provide further evidence of how repairs to the HVAC system can achieve energy savings. Utility bill analysis is not available for the seven homes analyzed in this part of the study, but improvements in system and equipment efficiency correspond with improved delivery of conditioned air. The data presented in this study help support the idea that individual components comprising a residential heating system act as a system and must not be looked at independently.

The data collected address the research questions as follows:

- Q: What is the current installed HVAC system operating efficiency, as defined by the capacity of conditioned air reaching building occupants?

  A: The installed system operating efficiency varies significantly in the 10 test houses in the second part of the study: from 40 to 80% at test-out. Clearly much work remains to be done to seal and insulate ductwork in these homes.

- Q: What is the achievable improvement in HVAC system operating efficiency from common modifications and quality installation of replacement of equipment?

  A: The increase in system efficiency from this study also varied significantly, but it appears from the results that it is possible to deliver 80%–90% of the heat generated by the furnace to the conditioned space (Table 5).

4.1 Next Steps

The findings of this study establish important baseline data about the potential gains in energy efficiency associated with HVAC equipment replacement and system tune-ups. In future research, these findings could be expanded upon by increasing the sample size, including more extensive utility bill analysis, and more qualitative information regarding system tune-ups. In the future this project will attempt to locate additional homes to include in this study to provide a more complete picture of the energy savings from system repairs and adjustments.

5 Conclusion

This project investigated energy savings potential in existing homes from natural gas furnace system repairs and adjustments that were recommended based on an initial evaluation of a furnace performance in-situ, or test-in. This evaluation of home heating and cooling systems involved measuring airflows, static pressures, and temperatures across the system to determine how well the furnace was performing compared to the manufacturers specifications. From the data collected it was determined that, on average, the homes that underwent the initial evaluation were not realizing 9% of the space heating energy potential available from their furnace, based on how it was operating at the time of test. Further examination of the initial evaluation showed that the majority of these losses can be attributed to either an undersized return or a restrictive filter. In 31 of the 48 homes, testing showed that a return that was too restrictive did not provide the required airflow across the heat exchanger, while 43 of the 48 showed that the in-place filter was overly restrictive.

In the second part of the project, the team examined a sample of 10 homes that had completed the initial evaluation for more in-depth study. In these homes, the furnaces were tuned or replaced and duct systems were modified. Four homes had equipment replacement and duct upgrades, and six homes had system tune-ups for both furnaces and ducts. For these 10 homes, the diagnostic data show that it is possible to deliver up to 23% more energy from the furnace to the conditioned space by doing system tune ups (furnaces and ducts) with or without upgrading the furnace. Replacing the furnace provides additional energy reduction. The results indicate that support the author's contention that residential heating and cooling equipment should be tested and improved as a system rather than a collection of individual components.

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Appendix A: Supplementary Data

Appendix A contains the supporting data for the seven additional homes analyzed in the third part of this research that were not included in the case studies.

Table 8. Supporting Data for 7 Additional Homes That Have Undergone System Tune-Ups and Equipment Replacement

		Test home # 4		Test home # 5		Test home #6		Test home # 7		Test home # 8		Test home #9		Test home #10	
		Mount Vernon, IA		Mount Vernon, IA		Lisbon, IA		Council Bluffs, IA 1		Council Bluffs, IA 2		Council Bluffs, IA 3		Council Bluffs, IA 4	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
AFUE	%	71	93	80	89	93	93	93	93	81	81	94	94	93	93
Rated Input	Btu	60000	45000	100000	52302	60000	60000	60000	60000	110000	110000	80000	80000	100000	10000
Rated output	Btu	48000	42000	80000	46319	56000	56000	56000	56000	89000	89000	75000	75000	93000	93000
Total ESP	i.w.c	0.57	0.73	0.85	0.5	0.56	0.49	0.74	0.55	0.5	0.5	0.5	0.5	0.5	0.5
Target ESP	i.w.c	0.5	0.5	0.5	0.82	0.5	0.5	0.5	0.5	0.6	0.62	0.81	0.81	0.7	0.64
Temp rise across the equip.	F	43.9	46	73.8	45.1	39.3	54.2	61	62	36	49	41	54	51	51
System Temp Rise	F	33.4	28.7	56.6	35.1	28.1	39.1	46.5	58.5	26.8	46.3	33.8	51.7	37.3	50.2
Supply reg ave temp	F	120.2	123.2	130.9	117.9	97.7	112.3	119	131	96.3	116.3	104.3	121.7	107.3	121.7
required fan airflow	CFM	780	675	1000	900	900	900	900	900	1430	1430	1200	1200	1500	1500
recorded fan airflow	CFM	1105	605	816	1045	1055	1078	852	853	1450	1450	1284	1284	1231	1450
Equip Adj Input	Btu	68965	44253	86539	52302	54369	73469	85714	64286	90000	105882	81818	81818	90000	90000
Equip Delivered BTU	Btu	35128	29756	56539	46319	42092	57423	56130	57117	56376	76734	56856	74883	67814	79866
Conversion Efficiency	%	51%	67%	65%	89%	77%	78%	65%	89%	63%	72%	69%	92%	75%	89%
System Efficiency- test	%	64	43	63	70	56	62	46	74	49	71	54	80	63	80
Equip manufactuer		ComfortMaker	Ruud	Singer	Trane	Carrier	Carrier	Bryant	Bryant	Carrier	Carrier	Carrier	Carrier	Carrier	Carrier
equip model		GUA060A012AIN	GRC - 04EMAES	2100-14MPD	060A9V3VAC	58MXA060-12	58MXA060-12	V036060FFKA	V036060FFKA	TA110-12116	TA110-12116	VB080F1-120	VB080F1-120	A100-F-17116	A100-F-17116

Appendix B: Topics Covered in the HVAC SAVE Training

Appendix B contains a basic outline of the topics discussed during MEEA's HVAC SAVE training.

DAY ONE

SECTION ONE – Introduction to Performance Testing

Review Typical Installation Practices and Effects on Performance

Introduce Appropriate Standards for Sizing Equipment and Ductwork

Review a Typical Service Call

Review Performance Studies

Explore BTU Measurements and Formulas Used Throughout Training

Introduce CommonCents Software

SECTION TWO – Measure and Interpret Static Pressure

Static Pressure Basics – Why Check?

Static Pressure Units of Measurement and Tools Required

How to Test Static Pressure in a System

Plotting Airflow Using Static Pressure

Static Pressure Drops

Top 10 Static Pressure Repairs

SECTION THREE – Identify and Plot Fan Airflow

Interpreting Manufacturer's Model Numbers/Nomenclature

Gathering Information about Equipment Potential Performance

Calculating Required System Airflow

Plotting Fan Airflow

Equipment Setup

The Impact of Airflow on Efficiency

SECTION FOUR – Airflow Measurement Methods

Tools and Specifications Necessary to Properly Measure Airflow

Introduce Air Balancing Hood

Basic Airflow Traverse Tools and Procedures

Complete Hand-On Airflow Measurements

Calculate Airflow Impacts on Efficient Performance

SECTION FIVE – Temperature Measurement and Diagnostics

Temperature Measurement Tools and Accessories

Measuring Temperature Change

Understanding Duct Loss / Gain Impacts

Temperature Profiling

Temperature Measurement Type

Combustion Efficiency

Common System Temperature Defects and Repairs

DAY TWO

SECTION SIX – Pressure Diagnostics and Duct Design

Benefits of Quality Installation Practices – Fixing the Whole System

Identify Common Pressure Problems Throughout the System

Complete a Total System Static Pressure Profile

Using the NCI Duct Tables for Redesigning Existing Duct Systems

Manual D Review for New Duct Systems

Typical System Repairs

Duct Requirements

SECTION SEVEN – Equipment Replacement & Commissioning

Common Load Calculation Procedures

Blower Selection Process

Determining Room by Room Airflow Requirements

Air Balancing and Proportional Air Balancing

Final Commissioning of System and Reporting

SECTION EIGHT – Putting it All Together (Sales and Service)

Discuss the Performance-Based Sales and Service Approach

Review Required Test Instruments and Accuracy Ranges

Review People, Roles, and Process Flow in the Performance-Based Process

Practical Pricing Strategies and Proposals

Appendix C: Data Collected During the Test-In and Test-Out Procedures

Appendix C shows a list of the data that is typically collected during the test-in and test-out process described in Section 3.

- Type of house
- Year house was built
- Total Sq Ft of the house
- Time of testing
- Altitude of the test location
- Typical thermostat setting for heating
- Outdoor conditions
- Manufacturers recommended CFM
- Type of heating equipment
- Furnace manufacturer
- Furnace model number
- Furnace serial number
- Furnace AHRI reference number
- CEE air handling ratio
- AFUE
- Rated input
- Rated output
- Furnace age
- Type of fuel
- Type of furnace
- Equipment's maximum rated total ESP
- Type of blower motor
- Blower motor size
- Blower speed setting
- Condition of the blower motor
- Location of filter
- Pressure before the air enters the filter
- Pressure after the air exits the filter
- Pressure where air enters equipment
- Pressure before the air exists equipment/enters the coil
- Pressure after the air exits the coil
- Return dry bulb temperature of the equipment
- Supply dry bulb temperature of the equipment
- Equipment airflow & method used
- Supply dry bulb temps at supply register(s)
- Return dry bulb temps register(s)
- Gas meter dial size and number of seconds per revolution
- % of supply ducts located in unconditioned space
- % of return ducts located in unconditioned space

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