Billing Analysis of Air Sealing and Duct Sealing Impacts

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This study is designed to assess the energy savings produced by air sealing and duct sealing treatments in the Home Energy Solutions (HES) program using billing data analysis. The analysis focuses on participants from 2007 and part of 2008. A prior billing analysis of 2006 participants found savings of about 40 therms/year for duct sealing and 27 therms/year from duct insulation. Air sealing was not a major program measure at that time.

Data Collection

The Energy Trust provided tracking system data and monthly gas and electric billing data for customers who participated in HES and received air sealing or duct sealing or duct insulation measures from 2005 through 2008. ETO also provide gas and electric billing data for two comparison groups: one composed of 2009 HES participants with actual post-treatment billing data removed, and one composed of a stratified random sample of non-participants. ETO provided daily outdoor temperature data from January 1, 2000 through March 31, 2009 for 11 local weather stations.

Program Treatments

The tracking data included 15,767 measure level records for 4,457 participants and included information about all measures from all ETO programs -- ranging from building shell measures to tankless water heater rebates to refrigerator recycling. The evaluation focused on the 2,328 participants treated from January 2007 though August 2008. To increase sample size, the analysis included participants treated from April through August 2008 even though less than a year of post-treatment data would be available. Screening criteria were used to exclude any cases without a balance of warm and cold weather.

Program treatments for the target group are summarized in Table 1 by heating fuel (which can be both) and by whether duct sealing or air sealing was performed. Building shell and duct leakage rates reported by contractors are also summarized in the table. This leakage data was first screened to eliminate likely errors and cleaned to cap very high values at high limits. Shell leakage rates were excluded if they were outside the range 800 to 10,000 CFM50 and remaining values were capped at 8,000 CFM50. Duct leakage rates were excluded if they were outside the range 20 to 8,000 CFM50 and values were capped at 4,000 CFM50.

Table 1. Program Treatments Summary

		Gas Heat			Electric Heat		
	All	All	Air Seal	Duct Seal	All	Air Seal	Duct Seal
# Participants	2,328	1,377	608	967	962	128	883
Manufactured Home	32%	6%	0%	7%	69%	0%	75%
Program Measures							
Air Sealing	**32%**	**44%**	**100%**	**60%**	**14%**	**100%**	**14%**
Duct Sealing	**80%**	**71%**	**95%**	**100%**	**93%**	**95%**	**100%**
Duct Insulation	39%	56%	50%	39%	15%	46%	7%
Attic Insulation	27%	39%	41%	30%	11%	35%	6%
Wall Insulation	7%	11%	14%	9%	2%	9%	1%
Heating Sys Repl/Upgr	16%	18%	14%	18%	13%	38%	11%
Floor Insulation	31%	45%	43%	32%	11%	38%	6%
Windows	7%	11%	11%	10%	2%	7%	1%
Hot Water Measures	26%	35%	38%	33%	14%	34%	10%
Lighting	36%	36%	39%	32%	37%	39%	36%
Projected Savings							
Projected kWh/yr	902	314	323	269	1,759	4,595	1,590
Projected therms/yr	93	156	188	147	4	4	1
Building Shell Air Leakage (CFM50)							
	n=690		n=562	n=531		n=124	n=118
Pre Treatment	3,069		2,997	2,987		3,407	3,415
Post Treatment	2,413		2,364	2,364		2,643	2,642
Leakage Reduction	655		633	623		765	773
Duct Leakage (CFM50 to outside)							
			n=551	n=842		n=120	n=293
Pre Treatment	869		907	887		974	819
Post Treatment	332		376	343		385	308
Leakage Reduction	537		531	544		590	512

Nearly all of the target homes received duct sealing -- 80% overall and 93% of the homes with electric heat. Air sealing was performed in about one third of all homes – 44% of gas heated homes and 14% of electric heated homes. Other common retrofits included duct insulation, attic insulation, floor insulation, hot water measures (mostly low flow devices but some replacements, including tankless, and clothes washers), and lighting. Less common treatments included wall insulation, window replacement, and heating system replacements, which also includes some heat pump commissioning.

Some of the patterns in program treatments pose potential problems for assessing savings by measure:

- None of the homes received air sealing as the only treatment.
- Duct sealing was performed in nearly every home that got air sealing – all but 31 of the 608 gas heated homes that received air sealing also received duct sealing
- Most HVAC contractors, and a total of 20 of the 46 contractors that did duct sealing, did not do any air sealing work.

- The largest air sealing contractor in the program performed one third of all air sealing jobs and specialized in doing just air sealing and duct sealing but did not do duct insulation or other building shell or equipment work.
- Most homes with electric heat were manufactured homes. Manufactured homes tended to receive only duct sealing with some lighting, and hot water measures. None of the manufactured homes in the electric heat target group received any air sealing or duct insulation or wall or floor insulation.

The lack of participants receiving just air sealing or receiving air sealing without duct sealing means that the estimation of savings from air sealing will depend primarily on how the savings differed between homes that got duct sealing but no air sealing to those that received both retrofits. To the extent that air sealing work is related to other factors, such as housing characteristics or specific contractors, air sealing savings estimates may be biased. For example, if the contractors that do air sealing tend to achieve lower savings from duct sealing than other contractors, then the air sealing savings will be underestimated while duct sealing savings will be over-estimated.

Building Shell and Duct Leakage Rates and Reductions

Reported air leakage reductions averaged 655 CFM50, a little more than 20% of the pre-treatment leakage rate of 3,069. Electrically heated homes that received air sealing tended to be a little leakier and achieve greater leakage reductions than the gas heated homes. Reported duct leakage reductions averaged 537 CFM50, equal to 62% of the average initial leakage rate of 869 CFM50. The tracking system did not have pre and post retrofit duct leakage information for most electrically heated manufactured homes leading to smaller samples.

Program testing standards do not require that ducts be masked off or the duct testing fan be sealed when performing the building shell leakage test. If one assumes that at least the testing fan is open, the reported shell leakage rates include a significant fraction of the duct leakage to outside. The reported initial duct leakage is equal to 30% of the initial shell leakage. However, during a shell leakage test the duct leaks would usually experience pressures of less than 50 pa, especially in leaky systems. If one assumes a 25 pa pressure during the initial shell leakage test, then duct leakage would have contributed about 20% of the pre-treatment whole house leakage on average. If one assumes a 40 pa pressure after duct sealing, then the duct leakage reduction should have reduced measured shell leakage by about 250 – 300 CFM50. Reductions of this size imply that about 40% of the reported building shell leakage reductions are actually duct leakage reductions counted twice. Infiltration modeling suggests that the annual gas heating savings expected from the reported shell leakage reductions might be about 40 therms per year. But if duct leakage reductions are excluded from this (and accounted for as part of duct sealing impacts), then the projected savings from the shell leakage reductions would drop to about 25 therms per year. The deemed savings value for air sealing in the tracking system was 25.5 therms, so perhaps no adjustment of expectations is needed.

Analysis Approach

The billing data were separated into pre and post retrofit periods based on the starting and ending measure installation dates for each participant. For the comparison groups, two pseudo treatment dates were randomly assigned to each customer – one from the 2007 participants and one from the 2008 participants – allowing comparison cases to be used for each year of the program. Pre and post treatment meter readings were eliminated if they occurred more than 14 meter readings and 450 days before or after the actual or pseudo treatment date.

The pre and post treatment gas billing data for each participant and comparison group customer was weather-normalized using a variable-base degree day regression model similar to PRISM. This model differs from PRISM in that it employs a Bayesian approach to estimating the balance point temperature which helps to avoid extreme balance point temperature estimates. Electric usage data were analyzed using a heating and cooling degree day adjustment method based on aggregating usage and degree day data into three seasons (winter, summer, and neither) and then solving for baseload, heating, and cooling slopes. Heating degree days were calculated at base 60°F and cooling degree days at base 70°F.

Weather normalization results were screened for reliability by removing cases where:

- the gas regression model fit was not very good -- R-squared <0.70 or CV(total)>20% or CV(heat)>100%
- there was insufficient data -- for gas: <180 days or <40% of a normal year's HDD or (max HDD/day- min HDD/day) < average HDD/day; for electric: <=270 days, <40% of normal year's HDD or CDD, no true baseload months.
- the usage was inconsistent with an occupied single family home heated by the specified fuel – for electric total >70,000 kWh/yr or heating <2,000 kWh/yr; for gas total <300 therms/yr or negative baseload or heating;
- the change in total usage was greater than 65%
- the total usage was outside the range of usage found among participants (only applied to comparison groups).

The data screening resulted in usable gas weather normalization results for 605 participants, 1,974 comparison group cases from future participants and 7,444 comparison group cases from randomly selected (stratified) non-participants. More than a third of the target participant group had insufficient data for the usage analysis – primarily due to the attempt to include homes treated through August 2008, most of which did not have sufficient usage data. About 10% of each group was lost due to usage outside the acceptable range. Poor usage data fits were responsible for just 7% of participant attrition and less than 0.5% of cases were excluded as savings outliers. Overall, 48% of target participants and more than 60% of each comparison group passed the screening criteria.

For the electric analysis, there were usable results for 334 participants, 594 comparison group future participants, and 5,270 random comparison group cases. There was insufficient usage data for the analysis for 38% of the target and future participant groups and 48% of the random comparison cases. Usage out of range was found for 8% of participants, 10% of later participants, and 30% of random comparison cases. Most of this attrition was apparent electric heating loads of less than 2,000 kWh, which screened out many random comparison cases that don't have electric heat and also likely screened out many participant cases that use supplemental fuels. About 2% of participants were savings outliers while just 0.1% of later participants experienced such large usage changes.

The basic analysis involved calculating the mean savings for the participants and then subtracting the mean savings of a weighted comparison group to estimate net savings. Comparison group cases were weighted to match the participant group using post-stratification on weather station (2 stations for gas and 3 for electric), pre-treatment annualized total gas usage (6 bins), electric usage components (6 bins for heating load and 6 bins for total load), and program participation year (2 years, to match comparison group cases from the same treatment date range). This weighted matching method provides a flexible way to improve the comparability of the comparison group without requiring many of the assumptions inherent in a regression-based adjustment approach. This stratification was performed separately in all savings break-outs for each cohort group analyzed, e.g., homes that received duct sealing have the comparison group weighted based on the distribution of strata for just the participants that received duct sealing.

Gas Savings

The most obvious and straightforward approach to assessing savings from duct sealing and air sealing is to directly analyze net savings for participants who only received those treatments -- preferably each treatment by itself. Of the 605 gas heated homes in the analysis, none received just air sealing, 65 received just duct sealing, and 93 received air sealing and duct sealing. These sample sizes are fairly small, especially for air sealing which only occurred with duct sealing. In addition to sample size concerns, the fact that most homes received more than just these treatments raises concerns about why these homes did not and how they may differ from the majority of homes. Table 2 summarizes the net gas savings for all participants that received air sealing and/or duct sealing as their only treatments.

Table 2. Net Gas Savings: Duct Sealing and Air Sealing (therms/year)

	# Homes	Pre	Post	Save	Net Savings	
Air Sealing Only	0					
Duct Sealing Only	65	634	569	65	**55 ±17**	8.7% ±2.7%
Air Sealing & Duct Sealing	93	772	733	39	**16 ±16**	2.1% ±2.1%
Comparison Groups						
- Duct Sealing Only	8,278	629	619	10		
- Air Sealing & Duct Sealing	6,954	767	745	23		

Notes: The later-treated and random comparison groups had nearly identical usage trends and so were combined into a single comparison group. All ± values are 90% confidence intervals on the mean.

The net annual gas savings are estimated at 55 ±17 therms from duct sealing but just 16 ±16 therms from the combination of duct sealing and air sealing. These results imply that air sealing actually reduces savings. We explored the data further to try to explain this unexpected result.

The homes that received just duct sealing had nearly 20% lower pre-treatment usage than the homes that received both treatments. This difference can be traced to the fact that the duct sealing only group includes 27 manufactured homes, which have lower usage on average, while the air sealing plus duct sealing group has no manufactured homes. Excluding manufactured homes from the analysis boosts the net savings even higher in the remaining 38 duct sealing only homes to 84 ±23 therms (12.3% ±3.4%).

A closer examination of the data revealed that one contractor (referred to as contractor Z) performed nearly all of the air sealing work in this analysis. Contractor Z specialized in performing only air & duct sealing work and not other treatments such as duct or building shell insulation. This treatment approach made them different from most other contractors and led to their jobs dominating the group of homes that received just these two measures. Table 3 shows the savings by treatment group, excluding manufactured homes, broken out by whether contractor Z performed the work.

Table 3. Net Gas Savings: Duct & Air Sealing Only, by Contractor Z

	N	Pre	Post	Save	Net Savings	
Duct Sealing Only – Contractor Z	9	614	544	71	**56 ±44**	9.1% ±7.1%
Duct Sealing Only – Not Z	29	713	604	109	**93 ±28**	13.1% ±3.9%
Air & Duct Sealing – Contractor Z	85	760	723	37	**14 ±17**	1.8% ±2.3%
Air & Duct Sealing – Not Z	8	897	839	58	**42 ±60**	4.6% ±6.7%

In both groups, the contractor Z homes had lower average savings than the other homes. However, there are just nine Z-treated homes in the duct sealing only group and eight non-Z homes in the air & duct sealing group. The small samples make the findings indicative, not statistically significant. Still, the results in the table show that the savings among homes that received air & duct sealing is largely driven by the low savings of contractor Z.

To the extent that contractor Z's work differs from other contractors or from the program design, the low savings found in homes treated by them may not help in making decisions about the current or potential value of these treatments. It turns out that contractor Z was actually suspended from the program in January 2009 due to poor work quality found in QC visits. Contractor Z also reported smaller leakage reductions than the other contractors:

- contractor Z reported less than half the average air leakage reduction of other contractors -- 381 CFM50 vs. 765 CFM50;
- contractor Z reported a 421 CFM50 average reduction in duct leakage, considerably less than the 583 CFM50 average reported by the other contractors.

If contractor Z homes are excluded from the analysis, there are just 29 homes that received duct sealing only and 8 homes that received air & duct sealing. The duct sealing only homes had surprisingly large savings of 93 ±28 therms equal to 13.1% of total gas usage and 17.5% of the 531 therm average heating usage. The 8 homes that received both treatments saved less than this, but the sample size is so small that the differences are not statistically significant.

The overall conclusions from this analysis of homes receiving just air and/or duct sealing are:

- poor quality air and duct sealing does not produce much energy savings;
- the program QC systems functioned properly in identifying a problem; and,
- program management apparently made a sound decision in suspending contractor Z.

The simple net savings analysis for homes that received only air sealing and duct sealing treatments provided some useful insights into program performance, but did not provide a very reliable assessment of the energy savings from air sealing or duct sealing retrofits done by contractors other than contractor Z. Rather than simply examine savings for homes that received only the two measures of interest, the savings from air and duct sealing can also be assessed for the larger group of homes that received additional program measures. For these homes, the savings from other measures needs to be accounted for in the analysis so that the incremental savings of air sealing and duct sealing can be estimated. We developed regression models of gas savings as a function of program treatments in an attempt to assess the impacts of treatments individually. We explored several specifications and fitting methods. One issue in this analysis is whether to include homes by contractor Z to assess savings retrospectively, or to exclude these homes and make the assessment more prospective. We explored both approaches

Table 4 shows the results from a series of regression models of gas savings.

Table 4. Gas Savings Regression Analysis

	Regression Model (see notes)					Models: no Contractor Z			
	OLS	R-1	**R-2**	**R-3**	R-4	R-1NZ	R-2NZ	R-3NZ	R-4NZ
Air Sealing	*-24*	*-12*	***-10***	***-13***	-26	*-7*	*-6*	*-13*	*-24*
Duct Sealing	48	41	**40**	**49**	56	38	38	48	55
Other Measures:									
Duct Insulation	40	36	**43**	**38**	31	*32*	40	37	*25*
Attic Insulation	69	81	**79**	**84**	85	78	76	83	82
Wall Insulation	78	67	**58**	**77**	78	67	58	78	79
Floor Insulation	*27*	39	**38**	**43**	41	36	37	42	39
Heating System Replace	118	85	**90**			90	93		
Window Replacement	*24*	*20*				*19*			
Hot Water Measures (all)	*-9*	*10*				*7*			
Other / Constant	*25*	*8*	***6***	***-14***	*5*	*16*	*11*	*0*	*17*
# Observations	605	605	**537**	**470**	438	502	434	368	336

Table Notes
Values in italics are not statistically different from zero at the 95% confidence level.
Dependent variable in all models is the measured gas savings from the pre/post billing analysis
Model definitions:

- OLS= ordinary least squares full model on full analysis sample
- R-1 = robust regression using Stata rreg command on same model as OLS
- R-2 = R-1 but excludes homes with window replacement or major projected hot water savings (>50 th)
- R-3 = R-2 but excludes homes that received heating system replacements
- R-4 = R-3 but excludes all manufactured homes
- NZ version of models are identical except all homes treated by contractor Z are excluded

The table shows savings ranging from 38 to 56 therms from duct sealing and negative savings for air sealing. The air sealing savings are not statistically different from zero for all models except R-4, which excludes manufactured homes. The exclusion of contractor Z from the modeling does not have a large effect on the estimates – air sealing savings estimates get slightly less negative and duct sealing and insulation savings decline slightly.

The shift in some model coefficients from using robust regression suggest that outliers have affected the OLS model. In model R-1, window replacements and hot water measures did not produce statistically significant savings. Model R-2 excluded the 68 homes that received these two retrofits. Model R-3 further excluded 67 homes that had heating system replacements. This model was specified because, although heating system replacements provided large and significant savings, the impacts may vary significantly from home to home and the retrofit may interact with the duct sealing and insulation measures in a variety of ways.   In addition, none of the manufactured homes in the analysis received a heating system replacement. Model R-4 was the same as R-3 but also excluded the 32 manufactured homes remaining. The increase in estimated duct sealing savings, decrease in air sealing savings, and decrease in duct insulation savings may be related to the fact that manufactured homes did not receive duct insulation or air sealing and also tended to save less gas than site built homes.

Regression models that attempted to estimate duct sealing or air sealing impacts based directly on reported leakage reductions were not successful in capturing any reliable or statistically significant relationship. However, a model (not shown in the table) that separated duct leakage reduction impacts between homes reporting high leakage reductions (800 CFM50) and those reporting lower leakage reductions yielded the same over impact estimate, but suggested that savings were nearly twice as large in homes that achieved large reductions than homes that achieved smaller reductions.

Model R-3 produced almost identical coefficient estimates for every retrofit whether or not contractor Z was included. Overall, model R-3 appears to provide the most reliable impact estimates and may be considered the best estimates of average gas savings from the retrofits. However, arguments could be made in favor of R-1 or R-2 depending on the importance one gives to a more representative sample compared to potential bias from collinearity between retrofits and housing characteristics.

The estimated savings by measure are similar to a prior billing analysis of 2006 participants that focused on duct sealing and duct insulation. That analysis found duct sealing savings of about 42 therms and duct insulation savings of about 28 therms.

The lack of savings from air sealing is a cause for concern and the exclusion of contractor Z homes did little to change the conclusion that the air sealing work was apparently ineffective or had negligible impact. The poor savings may be a result of biases related to the decision process to perform air sealing. If air sealing work was performed in homes that tended achieved smaller savings from the other retrofits, then the estimated savings may reflect the impacts of these other differences. This type of bias could be related to differences in contractors or housing characteristics. A lack of detailed housing information and the relatively modest sample size in this analysis limited our ability to pursue some of these potential issues. The analysis of reported leakage reductions indicated that a significant fraction of reported shell leakage reductions may have actually been double counting of duct leakage reductions. This finding may also explain some of the apparent lack of savings.

Electric Savings

The electric usage analysis produced savings results for 334 participants – 254 manufactured homes and 80 site-built homes. Given this skew the large fraction of manufactured homes and the need to identify electrically heated homes for the air sealing and duct sealing analysis, the later-treated participants should provide a much better comparison group than the random stratified sample where building type and heating fuel are unknown. An initial analysis found that the random comparison group experienced large changes in usage, especially in the estimated heating portion of the usage, and so the later-treated comparison group was used instead.

Of the 334 participants in the analysis group, 175 received duct sealing and/or air sealing as the only program treatments. That group is comprised of 165 manufactured homes that received just duct sealing, 7 site built homes that received just duct sealing, and 3 site built homes that received duct sealing and air sealing. Given this breakout of treatments, only duct sealing in manufactured homes may be evaluated as a single measure. Air sealing in general and duct sealing in site-built homes can't be reasonably assessed. The net electric heating savings for manufactured homes receiving just duct sealing are summarized in Table 5.

Table 5. Net Electric Heating Savings: Duct Sealing in Manufactured Homes
(kWh/yr for heating component)

	# Homes	Pre	Post	Save	Net Savings	
Participants						
MH Duct Sealing Only	165	6,687	6,088	599	**600 ±303**	9.0% ±4.5%
Comparison Group						
- Later participant MH	295	6,359	6,361	-2		

Notes: All values are kWh/year per home. All ± values are 90% confidence intervals on the mean.

Net heating savings averaged 600 kWh/yr for the 165 manufactured homes that received duct sealing as their only program treatment. This estimate has a fairly wide uncertainty with a 90% confidence ranging from 297 to 903 kWh/yr. In addition to this wide confidence interval, the analysis found net savings of 1,220 kWh/yr when assessing total electric usage rather than just the heating component. The large savings are due to an apparent savings in baseload usage. Although it is certainly possible for some heating savings to appear within the estimated baseload, this net savings appears larger than expected and remains unexplained.

We attempted to fit a variety of measure savings regression models to better estimate duct sealing savings and produce estimates of air sealing savings in homes that also received other program measures. This modeling was unsuccessful in finding any consistent relationships between the various program treatments and observed savings. Many of the treatments were performed in few homes and the inherent variability in electric usage and small samples made the effort fruitless.

Overall, the only conclusion that can be drawn from the electric usage analysis is that savings of about 600 kWh/yr were apparently achieved in manufactured homes but even this estimate has some potential reliability concerns.